TELESCOPE MAKING 11

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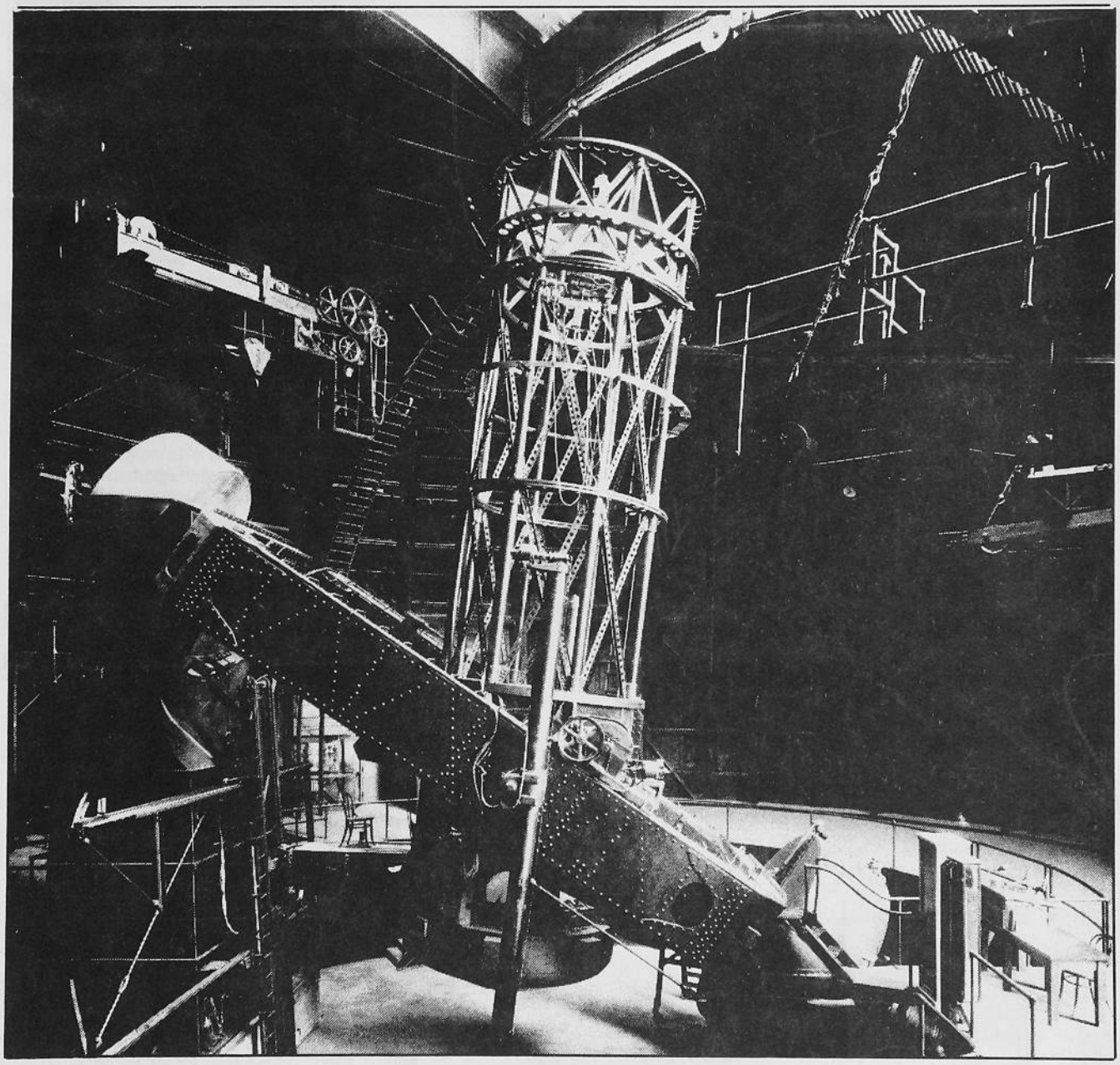
The magazine *for*, *by*, and *about* telescope makers!

Spring 1981



TELESCOPE MAKING

The magazine *for*, *by* and *about* telescope makers!

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Editorial

This issue, I have two important things to tell you. First, there's subscription rates:

The price of everything is going up these days. We're feeling the pinch, too, with rising printing costs and another third class mail postal rate increase scheduled for July. Beginning with TM #12, therefore, our subscription rate must go up to $10 per year. In order to play fair with our readers, we'll continue to offer subscription extensions and new subscriptions at the old rate ($8/yr, $16/2 years) until June 15. We hope you'll take advantage of this chance to save money if your subscription term is nearing its end, or if you feel it's simply economical to extend your subscription now. Please remind your friends who keep borrowing your copies of TM to get their own subscription before the price goes up.

Our new rate structure will offer an incentive to subscribe for two years. We have set this price at $18 to encourage longer-term subscribers. It costs us less to maintain your name on the computer than it does to send you a renewal notice and process your check.

To help you with a question I am very frequently asked, from now on the number of the last issue of TM you will receive will be printed on the mailing label. This should help those people who simply forget to renew, or call me asking when their subscription runs out. We'll have a little notice about this on the subscription form in each issue to remind you.

We're also going to introduce a new practice for our non-U.S. contributors. Since almost every one of you requests it, instead of paying you a $10 honorarium, we will add a year to your subscription. Bank charges for cashing

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U.S. checks come to most of the amount of the check.

Second, most of you probably noticed that TM #10 arrived rather late. Some people complained vigorously, in fact, and claimed all sorts of nasty things were going on. Let me explain a little bit about how TM is done. TM is a little magazine, with a "circulation base" of just a few thousand. For those of you who don't know it, the editor of TM (me), is also the editor of ASTRONOMY, a growing magazine with a worldwide circulation of about 130,000. Even when we founded TM three years ago, it was a "weekends and evenings" job for me to get it written and edited — in fact, I did most of the paste-up and layout as well as the editing — and the job of the editor has grown considerably since then.

Whenever there's an extra-big crunch with ASTRONOMY's schedules, TM now gets squeezed out entirely. For ASTRONOMY's January, February, and March issues, I covered the Saturn flyby at JPL, and was heavily occupied writing the feature articles after my return from smokey California. Even with help from our production crew from ASTRONOMY, TM#10 was ready to send to the printer about four weeks late. Then the printer, usually a model of efficiency, took three weeks instead of one week to turn the job around. It took our mailroom another week to label, sort, and mail because the magazine didn't "happen" when it's supposed to. It's the worst we've ever done. After that, of course, TM #10 traveled to you via third-class U.S. Mail.

This is the nature of TM. Nothing is going to change it, or make it possible for me to have the time I need to meet every deadline. We can't promise to get out every issue on time. Some issues will be prompt; others will not. A little understanding on your part would be greatly appreciated by our circulation department. Please be assured that TM is solvent, that we're good people, and the next issue is on the way.

What is the status of this issue? Today, ten days before it's due to go to the printer, we're right on schedule.

Sincerely,

Richard Berry

Richard Berry

Letters

Houghton Camera

Sir / I am delighted with TM#8 because of your article on the Houghton camera. My interests have always run more toward astrophotography than toward visual work (you should see some of the great dark skies in Idaho) and I have been contemplating the construction of a Schmidt camera for some time. Aside from the fact that I been able to find very little information on the construction of the Schmidt, I have not been looking forward to the task of making the Schmidt corrector or doing the subsequent testing and retouching that the system may require. (Nonetheless, I would appreciate any sources of information on Schmidt camera construction that you may be able to suggest.) I was happy, therefore, to learn of a plausible alternative to the Schmidt.

I would like to see additional future articles on the Houghton camera and I am wondering how one would go about obtaining a copy of Mr. Houghton's patent describing the fully-optimized version. I would also like to see some articles on the mechanical assemblies of Houghtons and Schmidts describing such things as film holders and corrector cells.

My renewal to your magazine for the next group of issues is presently in the mail so I will look forward to future TM articles.

Robert B. Dodson
P.O. Box 484
121 Hawthorne Avenue
New Plymouth, Idaho 83655

Dear Mr. Dodson / If you contact the patent office you can obtain a copy of the Houghton patent. It was issued in May 30, 1944 to J. L. Houghton, #2,350,112. Incidentally it was issued in England to the American firm Eastman Kodak Company!

I do not believe that the patent will be of assistance in your particular interest as it concerns special cameras for aerial reconnaissance. It is also general practice to "alter" the figures given in a patent so others cannot just copy and use the information, one is presenting a principle and not a "real" design.

I have been in correspondence with Jim Houghton for several years and recently asked him if he would prepare a special version of his camera for our readers to supplement the version by Dr. Buchroeder. His reply was that the Buchroeder version was more than satisfactory for amateur use and not enough would be gained to try to improve the performance by more design work. I must concur with him: making the fabrication more difficult for a minimal gain is not worth the effort. I suggest you make it as presented in TM-8, but employing a better grade of glass than plate in the corrector lenses.

The best material on the fabrication of Schmidt correctors is found in the Scientific American book of Amateur Telescope Making *— Book 3, pages 323-375. I suggest you obtain a copy if you intend to make a corrector.*

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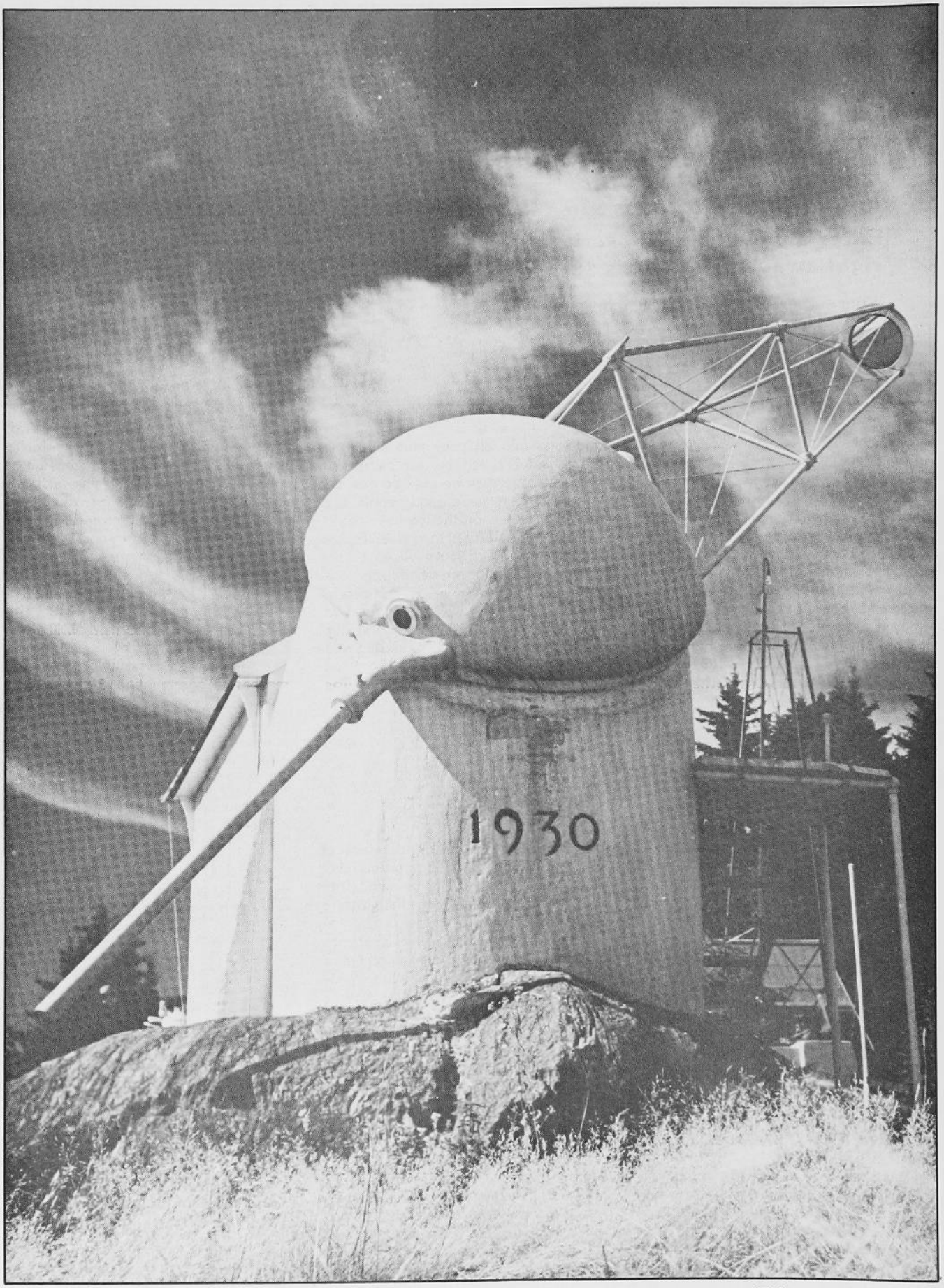

1930

STELLAFANE PAST and PRESENT

by Dave Eicher

photographs by Robert E. Cox

Some would say that an amateur's second trip to Breezy Hill in southern Vermont cannot quite match the magical feeling of a first Stellafane convention. But my second trip to the gathering last summer proved to be every bit as stimulating as my pilgrim voyage in 1979. Minutes after 12 noon on the opening day, even as cars rolled in, campers pitched tents, and registrants received their badges, the atmosphere on the legendary hill became one of camaraderie, companionship, and the finest moments of the year for hundreds of astronomers.

Anticipation transforms the slow trudge up the hill — greeting old and new friends along the way, and finally eyeing the old pink clubhouse — into a most assuredly exciting experience. You might hear Walter Scott Houston or other Stellafane veterans telling tales of observers and telescopes of long ago, while young teenagers can be seen proudly setting up their first Newtonians and eagerly unfolding star charts, impatiently and optimistically waiting for a dark, clear Friday night. Dennis di Cicco and his friends from the ATMs of Boston and the Springfield Telescope Makers can be spotted traversing the trail to insure that activities occur more or less as planned. While all of this initial restlessness went on about me, I decided to wander around and take in the people, the telescopes, and other noteworthy objects and happenings.

This year's gathering brought together a record 59 telescope entries on Breezy Hill, and numerous non-competing commercial and homebuilt scopes down in the camping area. There was the usual blend of Newtonians, Schmidt-Cassegrains, refractors, a few Maksutovs, and a handful of unusual instruments — in sizes ranging from 2-inch refractors to an 18-inch Newtonian brought all the way from California.

I was very impressed by the specially-designed observing chair fitted with a 3-inch f/5 refractor, providing comfort and convenient observing for practically every point in the sky. The design was similar to an observatory built years ago by the late Leslie Peltier. This chair was set up at the end of the rocky little ridge that supports the clubhouse, and owner John Riggs of Buffalo, New York attracted lots of attention with his creation. John also displayed a 6-inch f/7.5 Newtonian with a sturdy wooden tube and slideable focusing tube, a useful short cut in determining the exact point of focus and focal length of the mirror.

On the other side of the hill, the massive 18-inch f/4.6 open tube Newtonian brought by Kevin Medlock of San Loreno, California was the showpiece. This instrument, which has been displayed at lots of previous conventions, won 3rd prize for mechanical construction. After sunset, it provided breathtaking views of several

1937: The world-famous turret telescope atop Breezy Hill. Mr. Cox took the photo after staying up all night because all the bunks were already taken.
1958: Under the tent, John Gregory explains how to design a Maksutov telescope. At left is Allan Mackintosh, founder of the Maksutov Club.

Albert Ingalls, seated, answers the questions of David O. Woodbury, author of the Glass Giant of Palomar. 1948: Henry Paul shows members of the N.Y. AAA club his wide-angle camera. Stan Brower, one of the first employees of Perkin Elmer Corp., stands at left.

1980

deep-sky objects. Kevin's wife Denni brought an 8-inch f/7 Newtonian that won 2nd place in the optical judging. The 1980 gathering was the first in several years that telescope images were tested at Stellafane.

As August 8, 1980 passed, more and more observers carried up and assembled their scopes on the grounds where Russell W. Porter and friends once socialized. A bright blue fork mount held in place two telescopes constructed by Alan Bell of Essex Junction, Vermont — a 6-inch f/6.7 and 4.25-inch f/4, both Newtonians. The mounting is solid, and the convenience of being able to compare nearly simultaneous views through the twin-mounted telescopes is a very useful one.

One telescope that amazed people was the Multiple Mirror Telescope built by Ken Launie and Hal Robinson of the Boston ATMs. This telescope was displayed last year when less of the construction was complete. Although it is stil not fully operational, it soon will be. Its owners explained that the five mirrors used for the project combine their light-gathering abilities to produce a 14.4-inch f/7.4 scope. Inspired by the big MMT on Mt. Hopkins, Arizona, this amateur scope is certainly one of a kind.

On the first day, after a rushed dinner, I returned to the hill for a final look at some scopes. Adeland Rosseau of Montreal displayed a beautiful 6-inch f/14 Cassegrain that features a highly-polished aluminum tube and mounting — both practical and nice to look at. Bob Hoover of Harrisburg, Pennsylvania entered his 12½-inch f/5 Newtonian which he uses for observing deep-sky objects, and Kevin McLeod of Cranston, Rhode Island presented his 2-inch refractor perched on a Poncet mounting. Yet another impressive scope built by Perry Remaklus of Dundee, Michigan, was the 4-inch f/15 folded refractor with an impressive all-white equatorial head. This superbly crafted instrument won a 2nd place award for its mechanical construction.

Mr. Whipple explains his award-winning portable telescope to onlookers, including R.W. Porter, wearing hat.
1937: Albert Ingalls, left, and Russel Porter Sunday morning after the crowd had left. 6" RFT made by Robert Cox.

After a full day of telescope hunting and talking to fellow amateurs, darkness had fallen and several hundred observers gathered under the tent on Breezy Hill for the informal tent talks. Observing and astrophotography were popular topics, as we heard from various amateur astronomers and watched their slide presentations. The talks lasted well into the night, but as time passed the tent crowd dwindled as amateurs either uncapped telescopes aimed at the sky or retired to tents and hotels in anticipation of the following day's program.

Saturday, August 9, 1980 was a rather

TELESCOPE ENTRANTS
STELLAFANE CONVENTION: AUGUST 8-9, 1980
SPRINGFIELD, VERMONT

Data provided by Dennis di Cicco

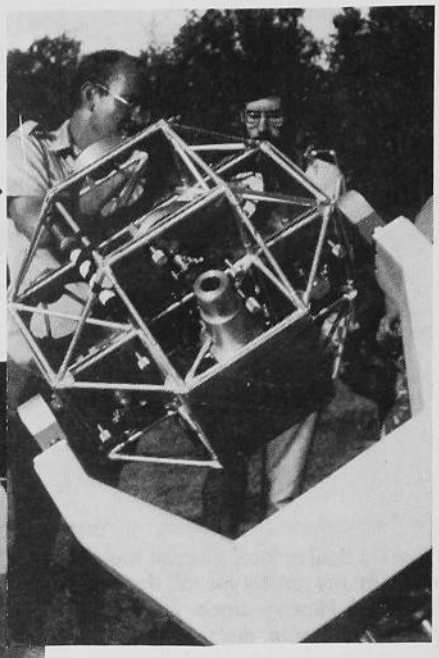
Entry #	Name	Address	Telescope Type	Awards
1	Kenneth Launie and Hal Robinson	Stoneham, Mass. Arlington, Mass.	MMT (14.4" f/7.4 4x6" + 1x8"	1st Special
2	Perry Remaklus	Dundee, Michigan	4" f/15 folded refr.	2nd Mech.
3	Nancy Waggoner	Detroit, Michigan	4.25" f/5.6 RFT	--
4	Shawn Dorkins	Worcester, Mass.	6" Newtonian	2nd Junior
5	Cary M. White	Sterling Heights, MI	6" f/4 RFT	Most innovative
6	John Staschke	Detroit, Michigan	6" f/5 Newtonian	--
7	Bill Elphick	Detroit, Michigan	2" f/10 Newtonian	--
8	Marty Kunz	Livonia, Michigan	4.25" f/10 Newtonian	--
9	Marty Kunz	Livonia, Michigan	4.25" f/10 Newtonian	--
10	Barry Carter	Detroit, Michigan	5" f/5 RFT refractor	--
11	Kevin McLeod	Cranston, RI	Poncet Mounting	--
12	Jack Brisbin	Canton, MI	6" f/4 RFT Newtonian	--
13	Jack Brisbin	Canton, MI	8" f/4.5 Newtonian	--
14	Steve Hubbard and Steve Siok	Westwood, Mass. Rhode Island	6" f/5.57 Newtonian	3d Mech.
15	Steve Spieker	Denville, New Jersey	8" f/4.75 Newtonian	--
16	Jerry Hill	Davison, Michigan	6" f/10 Newtonian	--
17	Stan Polczyk	Perth Amboy, New Jersey	6" f/6 Newtonain	--
18	George Chaplenko	Edison, New Jersey	8" f/3.9 Newtonian	--
19	Neil Hunt	Deep River, Ontario	4 1/4 f/12 (porter)	1st Junior
20	Peter Roduta	Townsend, Mass.	8" f/8 Newtonian	--
21	Peter Roduta	Townsend, Mass.	Poncet Mounting	--
22	Norm Remer	Southampton, PA	4" f/15 refractor	1st Optical
23	Mark Urbaetis	Rexford, New York	6" f/16 Cassegrain	--
24	Real Manseau	Drummondville, Quebec	Antique instrument	--
25	Real Manseau	Drummondville, Quebec		3rd Special
26	Allen Cuda, Bill Hunter, and Colin McArthur		10" f/5 Newtonian	--
27	Adeland Rosseau and Lionel Beaudoin	Montreal, Quebec	6" f/14 Cassegrain	4th Mech.
28	Arthur B. Lee	Needham, Mass.	10" f/5.6 Newtonian	--
29	John Riggs	Buffalo, New York	6" f/7.5 Newtonian	--
30	John Riggs	Buffalo, New York	3" f/5 observing chair	2nd Special
31	Andre Girard	Montreal, Quebec	6" f/5.35 Newtonian	--
32	Thomas Collin	Trois-Rivieres, Quebec	8" f/6.9 Dobsonian	--
33	Gerald Dyck	North Dartmouth, MA	solar viewer	--
34	Gerald Dyck	North Dartmouth, MA	blink comparator	--
35	Pierre Lemay	Hull, Quebec	8" f/5 Newtonian	--
36	Norman Fredrick	Claremont, New Hampshire	5.5" f/9 Newtonian	--
37	Denni Medlock	San Lorenzo, California	8" f/7 Newtonian	2nd Optical
38	Alan Bell	Essex Jct., Vermont	6" f/6.7 4.25" f/4 Newt	--
39	Yves Melancon	Drummondville, Quebec	Sun Dial	--
40	Tom Waineo	Chelmsford, New York	Null Test Paraboloid	Most Innov. Opt.
41	Kevin Medlock	San Lorenzo, California	18" f/4.6 Newtonian	3rd Mech.
42	William C. Schneider	Bayside, L.I. New York	6.4" f/15 Maksutov	1st Mech.
43	Robert Baker	North Grafton, Mass.	Radio	2nd Optical
44	Fred Baker	North Grafton, Mass.	Newtonian	--
45	Donald C. Dilworth	Medford, Mass.	16"	2nd Optical
46	Doug Welch	Toronto, Ontario	Spectroscope	--
47	David Kelly	Shelburne Falls, Mass.	3" f/15 refractor	--
48	Ernest and Kathleen Friedlander	Watertown, Mass.	8" f/7 Newtonian	2nd Mech. 2nd Optical
49	Robert Hoover	Camp Hill, Pennsylvania	12.5" f/5 Newtonian	--
50	Ricky Loiselle	Leominster, Mass.	2" refractor	--
51	Robert Dick	Ottawa, Ontario	12.5" Newtonian	--
52	Doug McGregor	St. Johnsbury, Vermont	8" Newtonian	--
53	Peter J. Kandefer	New Hartford, Conn.	Radio telescope	--
54	Patrick O'Reilly	Vernon, Connecticut	6" f/8 Newtonian	3rd Junior
55	David Schmidt	Hampden, Mass.	10" f/5.6 Newtonian	--
56	Vern Curry	Plaiston, New Hampshire	10" f/4.5 Newtonian	--
57	Scott Southard	Freeport, New York	Portable observatory	--
58	Alan P. Witzgall	North Bergen, New Jersey	10" f/4.5 Newtonian	--

uncluttered day — at least in the morning. Nothing much was going on apart from the informal socializing that always occurs. Our group wandered on down into Springfield for a late breakfast at the Idlenot Restaurant, a favorite convention hangout. After the noon hour, all bodies on the hill assembled once again under the tent for the formal talks. Several very interesting and slick presentations impressed delegates. Dave Healy's talk on astrophotography, Glenn Chaple's on double star observng, and Gerald Dyck's on using blink comparators were excellent. After the talks, we disbanded for an early dinner and time to reorganize before attending the closing session at the clubhouse and Porter Turret Telescope.

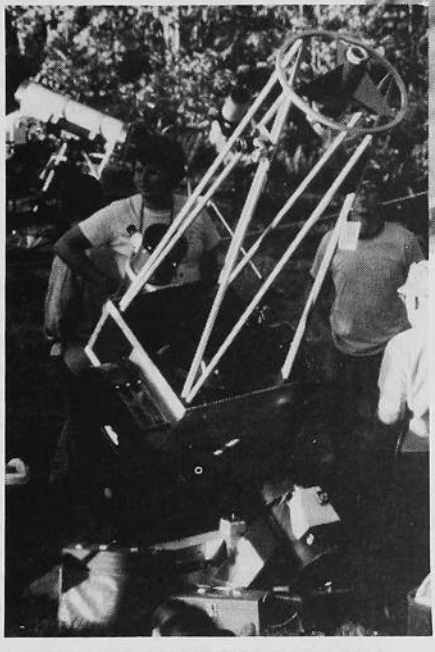
The talks began with the usual introduction by Gov. Joseph B. Johnson, and the "Shadowgram" by Walter Scott Houston — a reflection of conventions past and present. This year's feature presentation was a talk delivered by George T. Keene of Rochester, New York, who spoke on his solar eclipse trip to Kenya earlier in the year, and dazzled the audience with an elaborate and stunning display of travel

Norman Remer's 4" f/15 refractor won first-prize in the optical judging.

"The MMT" wasn't finished yet, but wait until next year.

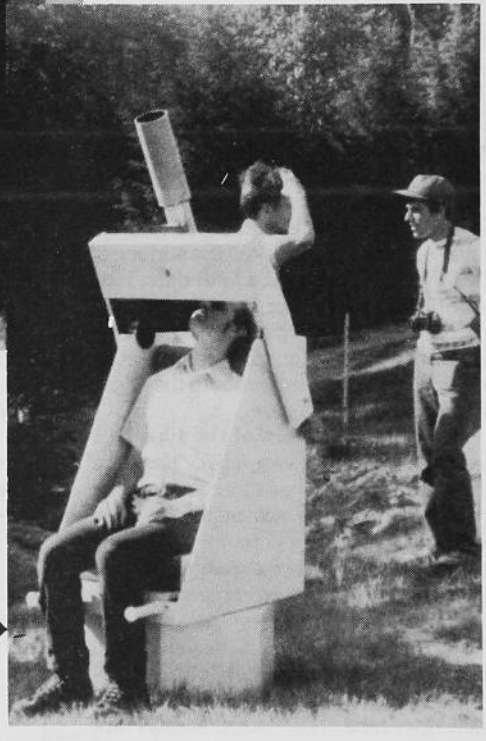


Perry Remaklus' stubby forked 4" f/15 refractor was mounted on an elegant solid mounting.



Kevin Medlock's 18" f/4.6 was the largest telescope on the Hill in 1980.

John Rigg's 3" f/5 refractor turns on bearings resembling those in a Dobsonian telescope.



slides.

All the while on this clear Saturday night, the Perseid meteor shower was decorating the Stellafane skies. Thus amateurs who sat under the stars to listen to fellow amateurs often found themselves interrupting with "oohs" and "aahs" when a bright Perseid streaked across the sky.

When all the talks were finally over, my group opted to stay up and observe — particularly for the chance to look through the two image intensifiers attached to telescopes on the hill. Having gone through the formal part of Stellafane, we didn't want to miss out on the real thing. Across the hill and down in the campground, many amateurs trained their optics on various celestial objects — the very reason for Stellafane. Many observed for several hours, others continued throughout the night. After all, they realized that as of the next day another year would pass before they could return to Stellafane.

Editor, Dave Eicher
Deep Sky Monthly
104 Oakhill Drive
Oxford, OH 45056

■

Notes on the Jones-Bird Telescope

A great deal of local interest has been shown in my prototype 6″ Jones-Bird telescope. Having since fabricated a 12.5″ system and developed practical methods of assembly, the following may be of assistance to others who make one of these designs.

Employing the methods I outlined in TM#2 for making lenses, fabricating the two elements and primary needed for the 12.5″ went off without a hitch — almost. One problem did arise: in order to see the full aperture in testing, it was necessary to make the test surface about 2/3 the lens diameter. I didn't bevel the edge of the test plate as much as I should have — and its edge nicked the surface of the lens in handling. At a later date, I will rework this surface or replace the lens. To prevent such accidents, be sure to bevel adequately. Rounding them is even better, but in any case, smooth the edges before using a test plate.

The mirror cells are of the type that use push-pull screws for mirror tilts. The primary mirror cell has three screws that thread through the rim of the cell and bear on the mirror's edge for centering, while small clips hold the glass in the cell. The diagonal mirror is cemented to its supporting hub.

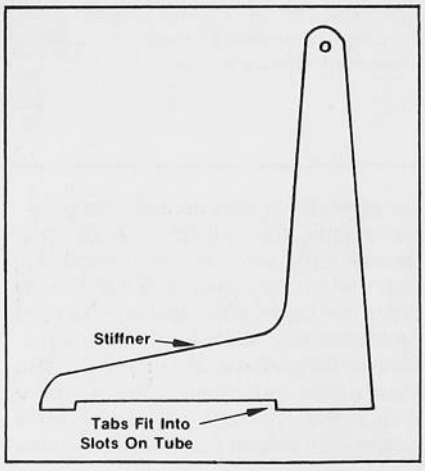
The primary mirror is installed in a short length (3 to 4 inches) of tubing of the same diameter and type as the telescope tube. The edge screws are then adjusted (measurements being made with a telescoping gauge), until the mirror is centered. A small dot is painted on the exact center of the mirror face to assist further alignment.

The lens cell and diagonal are mounted in a lens tube that has the spider arms attached to it. The spider arms are held in the large tube with conventional forked screws, pins, and nuts. In the 6″ instrument, the arms and lens tube were made of brass and soldered together. The 12.5″ has a fiberglass/epoxy tube and the micarta arms are epoxied to the tube. A micarta tube can be used if you feel like paying the minimum order at your supplier.

In placing the lens-diagonal tube in the large tube, it was found that alignment of the assembly was critical and time-consuming. Some type of mechanical assistance was needed to help accuracy and speed up the work. I made up two alignment disks, labeled A and B in the drawings, and machined them to fit snugly into the interior of the large telescope tube. Disk A has a boss at its center that has a snug fit into the lens tube, while B has a central hole that is a snug fit around the lens tube.

Four slots were cut into the lens tube. These accept the spider arms and were made with a small slitting saw while the tube was held in an indexing head on a tool grinder. The hole for the light leaving the diagonal and all mounting screw holes were also made at this time.

After careful measurements, the four holes for the spider bolts are drilled in the main tube. The hub on the forward disk, A, has the lens tube slipped over it and the unit slides into the large tube. Two of the spider arms are put in the slots permanently after their screws are attached, and two are put in temporarily to allow the assembly to be tilted out of the tube later. The two temporarily mounted screws must be marked so they can be oriented properly when reinstalled.



The outer alignment disk, B, is now attached to the lens tube and the disk is slipped into the main tube. If all has been done correctly, the lens tube will be in the proper position, centered, and axially located in the telescope. For convenience in working, align the outer disk so its access holes are lined up with the spider arms.

The brass assembly is soldered, allowed to cool and removed. But don't use a torch — excessive heat will anneal the brass. The fiberglass unit should be epoxied two arms at a time so the resin won't run. When all resin has been applied, leave the unit undisturbed for one week to prevent shifting due to shrinkage. The spider can now be removed and painted black.

To align the system, first center the tube on its mechanical axis by the use of two disks with small pinholes that are taped over each end of the tube. An illuminated pinhole is placed in front of the unit at a distance equal to the radius of the mirror from the mirror's location in the tube. Get behind the assembly, and look through the pinholes, then move the tube until you see the lighted hole. Lock the tube in position and, after checking to see that nothing has moved, remove

the two disks from the tube. Mount the mirror and its cell at the proper end of the tube and tilt it until the reflected image of the lighted pinhole returns upon itself. The optical and mechanical axes of the instrument will now be in coincidence!

Put the spider in place, followed by the alignment disk, B. Adjust the arms to a moderate tension, then remove the disk.

The lens cell is now inserted in the small tube and set the correct distance from the main mirror. Finally, the diagonal is installed and set. I recommend that you do this with a reflecting eyepiece. On star testing, one instrument had some flare that was removed with a tweak of the diagonal, and the other needed no adjustment.

Tests showed that moving the lens forward and backward small amounts made no noticeable change in image quality but did result in large changes in the focus position.

If you have trouble in obtaining brass tubing in small pieces, one source of supply I know will sell one foot lengths is: Craftsman Speciality Supply, 6608 Forty Mile Point, Rogers City, Michigan 49779. They stock telescoping sized by 1/16" increments from ½" O.D. through 2 ½" O.D.

Several people have asked me if this or other catadioptric telescopes can be successfully completed without access to machine tools. I frankly doubt it. Most of them are sensitive where centering and tilt are concerned, and because of this, machining is the only practical approach. An exception to this would be the CHT (Catadioptric Herschelian Telescope) where only a drill press is needed.

Jim A. Wilson
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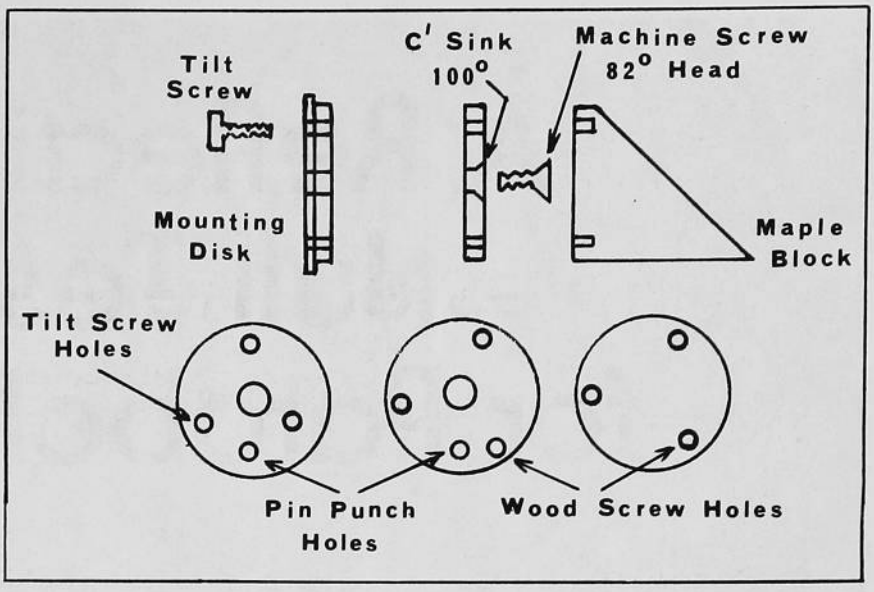
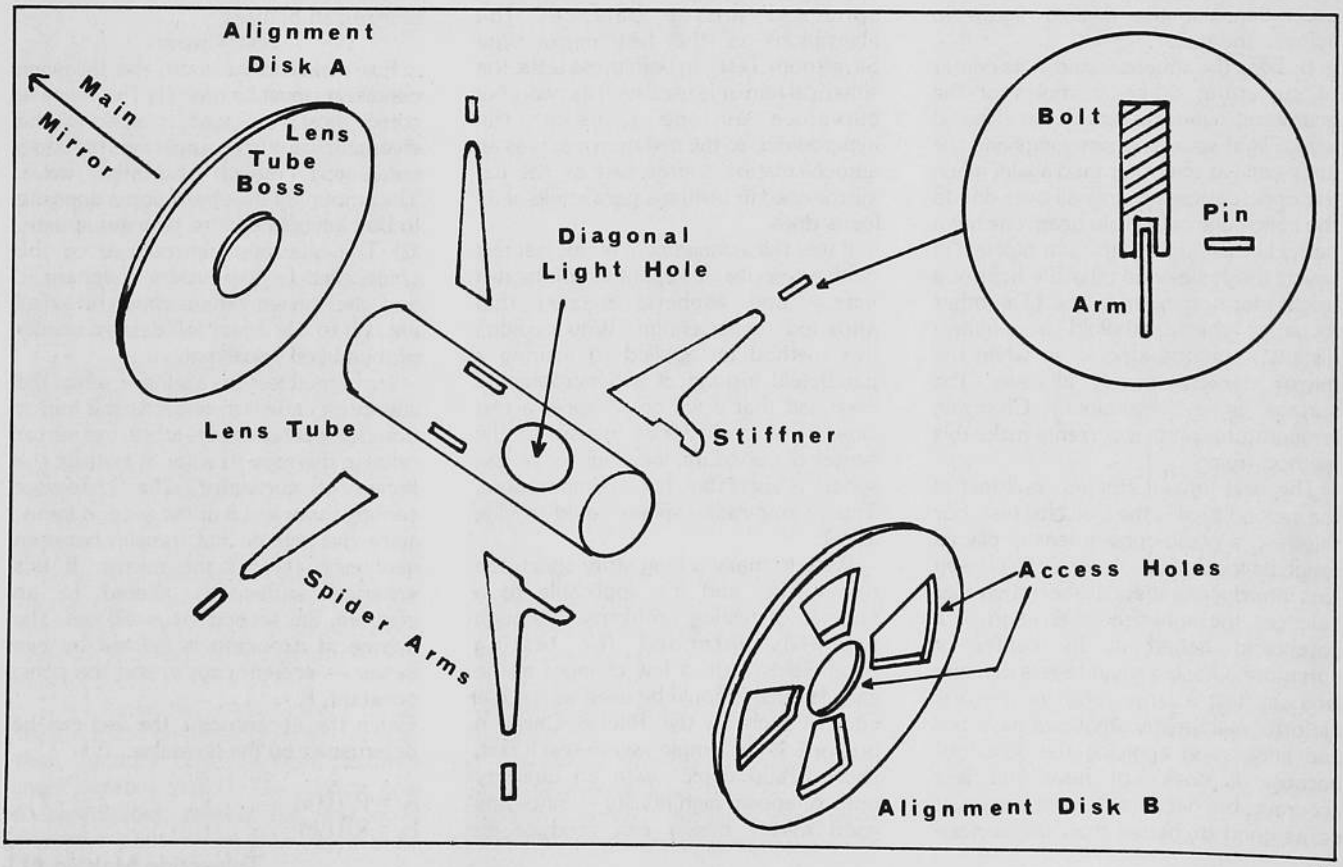
Hazelwood, MO 63042





A Reflecting Null Test for Paraboloids

What is a null test? Opticians have long used the Foucault knife-edge test at the center of curvature of a mirror in testing. If each of the rays returning from the mirror is cut by the knife-edge, the surface darkens evenly. For the sphere, the Foucault test is a null test. Any imperfection on the surface is seen as a shadow or bright area — which the optician can evaluate and remove by proper figuring.

A null test can be applied to other conic surfaces. There are two types; the first makes use of the geometric foci to produce a null, the other makes use of introduced aberrations that balance the aberrations of the desired figure to achieve the null.

Besides the sphere tested at its center of curvature, other examples of the geometric null tests include an ellipsoid with a light source at one focus and the knife-edge at the other (and again, when the optic darkens evenly all over due to the knife-edge in the light beam one has a perfect ellipsoid), and the star null test in which the knife-edge cuts the light of a bright star coming to focus. (The other focus of the paraboloid is infinitely distant — at the star — so when the mirror darkens evenly all over, the surface is a paraboloid.) Changing temperatures and air currents make this method trying.

The best known amateur null test of the second type is the Dall Null test. For this test, a plano-convex lens is placed inside its focal point. A correctly chosen lens introduces spherical aberration that balances the spherical aberration of a paraboloid tested at its center of curvature. One big advantage is that one lens can test a large range of mirrors. Unfortunately many amateurs have not had success in applying this test, not because it does not have sufficient accuracy, but because the test lens must be as good or better than the surface under test. Remember: No null test can be any better than the quality of the auxiliary optics used to perform the test.

If a null test can be performed using a lens, it can also be applied using the mirror optics. One such test is described in *Optical Shop Testing*, by D. Malacara, in chapter 14. The tests presented in this book show the null mirror placed behind the center of curvature of the mirror under test with one exception, the tests for a concave or convex hyperboloid.

Of these tests, the Hindle Test provides a null for a Cassegrain secondary using a spherical mirror, (see TM-1 pages 10, 12, 13), and for concave spherical mirror balances the aberrations of the test mirror (the Silvertooth Test). In both these tests, the spherical mirror is used with its center of curvature at one focus of the hyperboloid, so the test mirror acts as an autocollimating source just as the flat mirror used in testing a paraboloid at its focus does.

It was the arrangement of this last test (with a reasonable separation of the test mirror and aspheric mirror) that attracted my attention. Why couldn't this method be applied to figuring a paraboloid instead of a hyperboloid? I reasoned that if we could apply a test close to a conic focus instead of the center of curvature, we would have less spherical aberration to be compensated. Thus, a long-radius sphere could provide a null.

Well, to make a long story short, the test works, and it's applicable to a number of testing problems. Although primarily intended for testing paraboloids, with a few changes in the calculations, it could be used with other conics, such as the Ritchey-Chretien primary. It is a simple way to test a fast, short f/ratio conic with an auxiliary optic of known high quality — since any good mirror maker can produce an excellent spherical mirror for this null test!

As with other aberration balancing nulls, before you apply it to novel test situations, the residual aberrations should be determined to find the optical path differences in the nulled wavefront. Balancing only the 3rd order aberrations is not sufficient. We have calculated the residuals , however, and they are quite small: for a 6" f/4 paraboloid, the 5th order optical path difference is about 1/400th of a wave, and all the higher orders amount to about 1/300 wave. With reflecting optics there are no color aberrations, so any wavelength or color of light can be used.

Test Theory

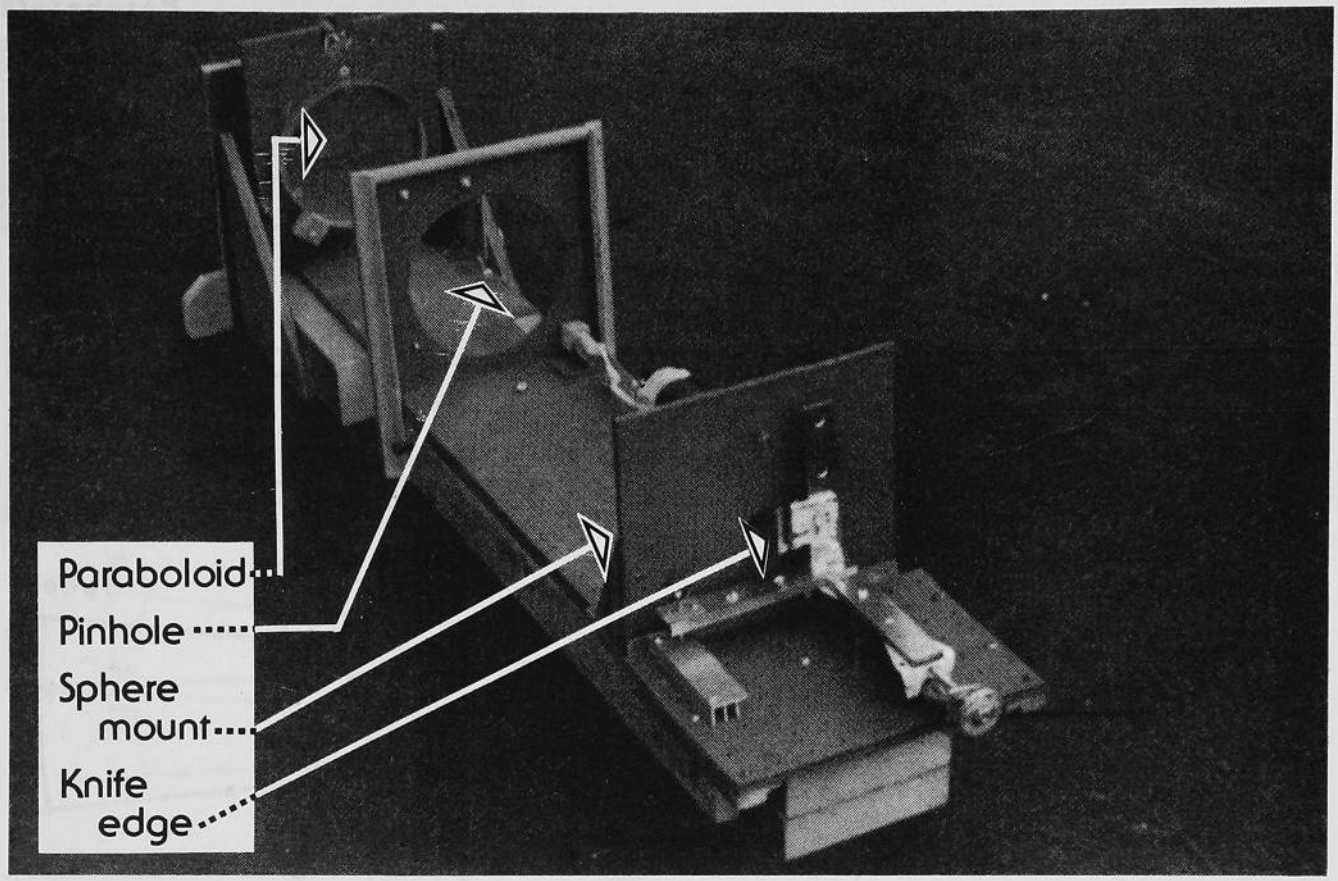
For a null to function, the following conditions must be met: (1) The concave conic must, by itself, transform the divergent wave from a point source into a converging, though aberrated, wave. The amount of the aberration is opposite to that introduced by a concave sphere. (2) The aberration introduced by the conic must be low orders of spherical, and the higher orders must be small enough to not affect the desired quality of the nulled wavefront.

In the null test for a sphere, when the source is moved in towards the mirror from the center of curvature, the mirror returns the rays to a focus outside the radius of curvature. The knife-edge cannot show a null at the second focus, since the rays do not transfer between geometric foci of the mirror. If this spherical surface is altered to an ellipsoid, the second focus will null. The degree of alteration is defined by two terms — eccentricity, e, and the conic constant, K.

Given the eccentricity, the foci can be determined by the formulae:

$F_1 = R/(1+e)$

$F_2 = R/(1-e)$



Or if the radius and foci are given, the eccentricity can be found by either of two formulae:

$e = (R/F_1)-1$
$e = 1-(R/F_2)$

The conic constant is related to the eccentricity by the relationship:

$K = -e^2$
$e = (-K)^{0.5}$

For a sphere, e = 0 and K = 0. For an ellipsoid e varies from 0 to 1 and k from 0 to -1.

When the source moves closer to the mirror the second focus rapidly moves away from the mirror. When one source reaches a distance half the radius of the mirror, the moving focus reaches infinity. If the mirror nulls the light, e = 1 and K= -1. The curve is a paraboloid and the second focus lies at infinity. A flat can be used to return the rays to the mirror and be reflected them back to the source at the focus. This is the autocollimation test, an example of a null test of the second type.

If we move the source closer to the mirror, the eccentricity, e, is now greater than 1 and the conic constant becomes more negative than -1. The surface, now a hyperboloid, reflects the rays on a divergent path — but if we trace them back behind the mirror, we find the virtual focus. In the formulae, we represent it with a negative value.

Examination of the foci of the various conics reveals that one could obtain a null test by combining the geometric foci of an ellipsoid and hyperboloid. Few, however, would care to figure a second aspheric for testing even if a null test could be used to figure the aspheric. It is possible to substitute a sphere for the ellipsoid in an autocollimating mode — but then one obtains a hyperboloid rather than the desired paraboloid. Is there some way to use a sphere and still obtain a null test for the paraboloid?

Yes, if one retains the geometric symmetry of the hyperboloid and the ellipse, but replaces the two mirrors by a sphere and a paraboloid respectively. If we do not change the vertex radii of the mirrors, the paraxial foci are not changed. Imagine that we make the change.

The F_2 focus of the now-parabolic mirror has spherical aberration because it is operating at elliptical conjugates; and the sphere has spherical aberration due to its operating in the mode of a hyperboloid. The trick is to make them balance out.

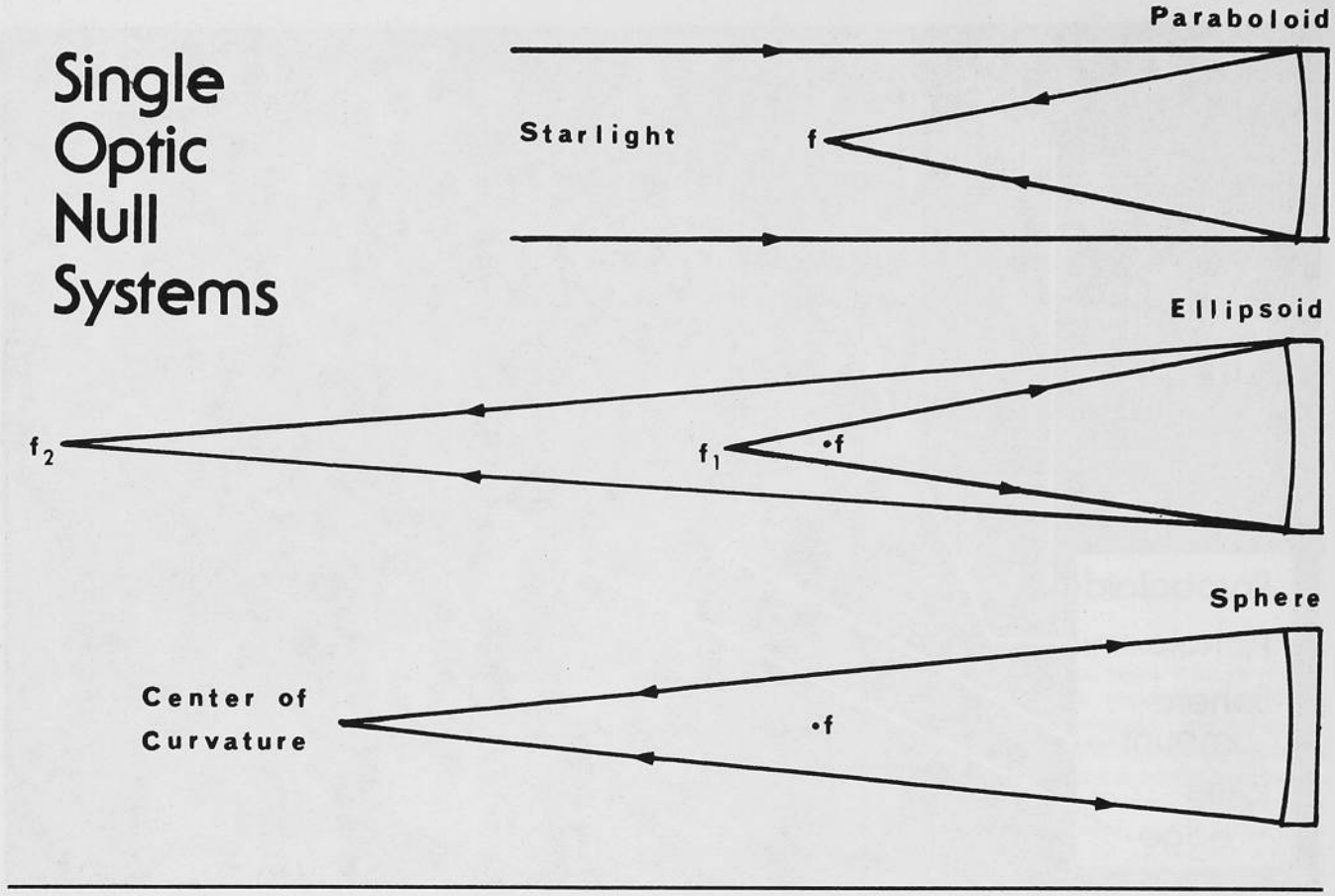
We cannot balance every ray, but we can come close. If we simply compute a system whereby the paraxial (center) and the marginal (edge) rays share the same foci, we will have corrected the 3rd order spherical aberration of the system. Residual spherical of higher orders will remain, but hopefully will be small.

What can we do with the sphere so that it will balance the 3rd order? We could change the radius until the paraxial and edge rays meet. Or, we could leave the radius alone and move the sphere until the two rays meet. This is accomplished by moving the sphere until the edge collects the marginal ray. If the sphere's radius is not able to compensate for the spherical, then we must try a new sphere diameter and move it again.

The the computer program developed to carry out this calculation, the 5″ sphere for testing the 6″ f/4 paraboloid was moved by the program 34 times and 12.7″. The diameter of the sphere was reduced to 4.3″, and the last move was only 0.00029″.

Once a system has been computed, we must examine it to see if it can be used. If both foci fall between the mirrors, then a diagonal is needed to bring the rays out the side for testing. If we could find an F_2 so that the conic focus falls just behind the sphere, then we could perforate the sphere to bring the rays through. Next, we must look at the sphere's focus to see if it falls between the mirrors and is a suitable place for our light source. We may be forced to change the sphere's radius if it is so long

Single Optic Null Systems



that the focus falls behind the test mirror, which we do not wish to perforate.

We're in good shape if we can compute a sphere between 2/3 and 3/4 the conic diameter and within 30% of the radius of the conic. A practical null is one in which F_2 is 15 to 50 times the conic diameter.

To compute a null system we need to know F_2, paraxial focus; the primary semidiameter, Y_p; the radius, R_p, of the paraboloid; and either the spherical mirror semidiameter, Y_s, or the radius of the sphere, R_s. For each value of F_2 we can compute a null so there are an infinite number of solutions for a paraboloid. The separation of the two mirrors is determined roughly by the formula:

$$S = F_2(Y_p - Y_s)/Y_p$$

This is an approximate separation; the final one will be calculated by ray tracing. The F_1 focus can be found by the ellipse formula or the object-image-focal length equation:

$$1/F_2 = 1/F - 1/F_2$$

Where F_1 is the mirror focus and F_2 and F_1 and the two foci being applied.

The first ray is determined by connecting a point on the paraboloid to the F_1 focus. By determining the proper angles, the direction the ray leaves the paraboloid can be found. Along this ray, the aberrations are balanced by the use of sagitta (depth) differences, and the proper radius or size of the sphere is determined. The ray trace is then continued. If there is a variation of the marginal and paraxial focus, a correction may be applied to the size or radius until the variation is within a predetermined limit.

To properly balance aberrations we need to compute the surface departures measured along the normal to the wavefront. For convenience let us do the improper and determine the departure along the marginal ray. If the ΔL (L being the distance from the center of the sphere to the F_2 focus) then the ΔX (sagitta depths) are equal. We can assume that the sagitta differences measured parallel to the axis can represent the spherical aberration to be balanced along the normal to the wavefront.

After adjusting the balances of sagitta the final check is to find ΔF_1, we find the difference between the paraxial focus and the marginal focus. If this figure is less than one millionth of an inch, a null test system has been computed. If this condition has not been met, then a change in the parameters must be made and another calculation made.

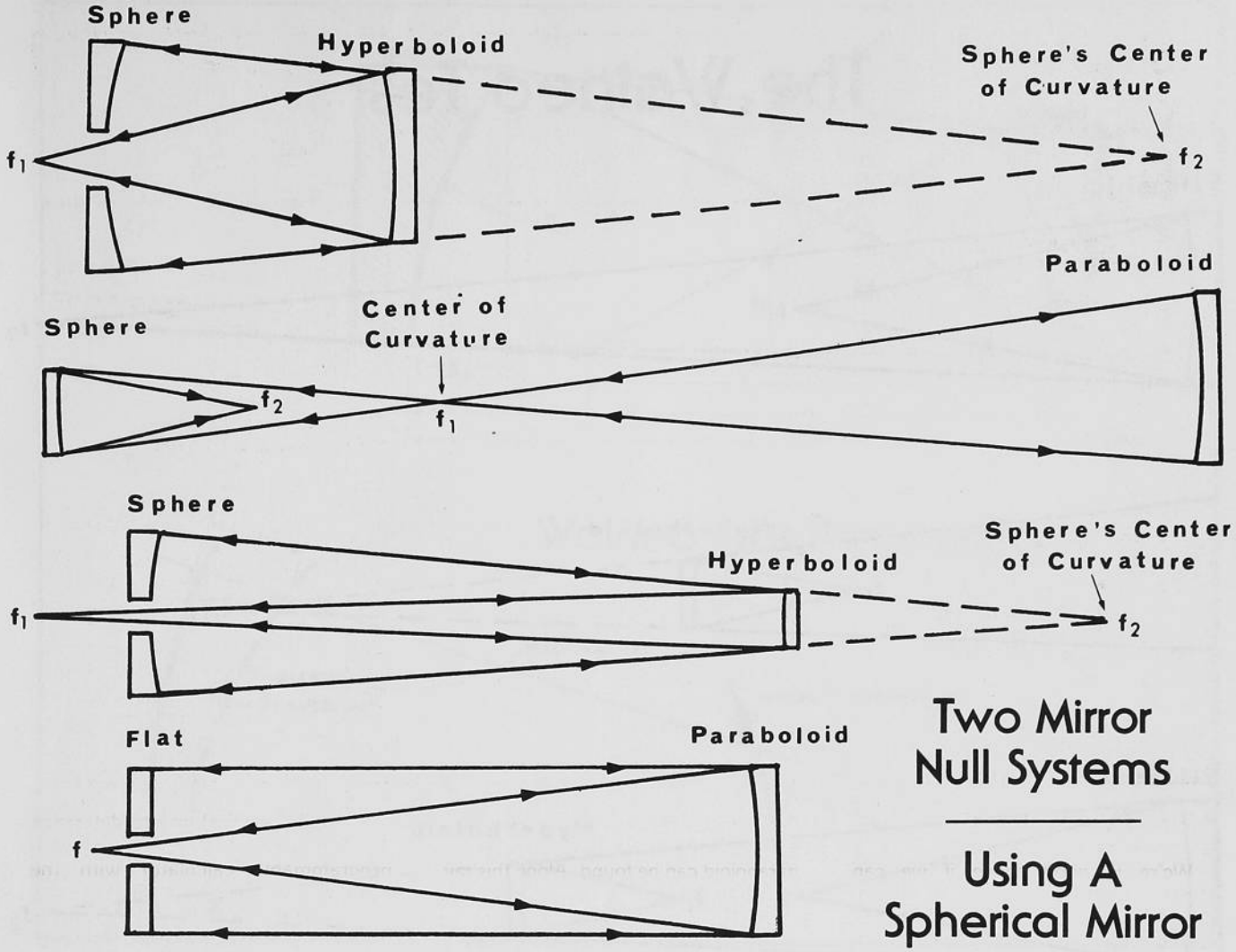
The only practical way to determine the test parameters is the use of a programmable calculator with the capability of internally looping and recalculating until a specific condition has been met. This approach solves the problem entirely by ray tracing.

With a program that I have developed for the Texas Instruments 58C calculator, only five basic entries are needed to run an analysis. After the height of a light ray on a paraboloidal mirror, Y_p, is entered; the radius of the paraboloid (central or paraxial zone), R_p; and a distance F_2 selected, then either the height of the ray on the spherical mirror, Y_s, or the radius of the spherical mirror, R_s, is entered, and a rough value specified for the variable parameter.

After running, the program will print out the system null data. (If a printer is not available, then the data can be manually recalled from the storage memories of the calculator.) Running time for a typical calculation is between two and five minutes. The closer the original parameters to the final solution, the shorter the running time required as less internal looping is required.

Checking the Null

As previously mentioned, balancing the third order aberrations is sufficient. Since the maximum longitudinal spherical aberration occurs near the 70% zone on the paraboloid, we can quickly



Two Mirror Null Systems

Using A Spherical Mirror

check the quality of the null. The minimum aberration due to 5th order (and also the minimum O.P.D.) is found by the formula:

5th order OPD = $((LA_{max})(\sin^2 U_3))/24$

with LA the longitudinal spherical aberration, and U_3 the angle made by light ray from the source to the ray height on the spherical test mirror.

Generally, in running the T158C program after F_2, Y_p, Y_s, and R_p have been entered, if the starting figure chosen for R_s is the same as that of the paraboloid, then the calculations will balance out and compute any changes needed in the radius of the sphere reaching a final null condition.

For practical reasons, it is best to adjust the location of the mirrors so the F_1 focus is longer than the separation of the mirrors S. This arrangement of the test, the one I demonstrated at the 1980 Stellafane, gives the best the parameters and is shown on the TI58 computer tapes. Note that three locations for F_2 have been run and three solutions obtained, each of which is a satisfactory null!

Doing the Test

To set up the null test, first set up the sphere and pinhole with the pinhole at the calculated distances from the mirrors. Looking at the spherical mirror from the radius of curvature, adjust it until the pinhole is centered. Place the whole assembly in front of the paraboloid at the proper separation and adjust it so the pinhole and sphere centers are aligned with the paraboloid centered. Finally, adjust the paraboloid until the final focus comes through the center of the hole in the sphere. If all the parameters have been measured carefully (a tape measure is as accurate as necessary,) the final image will fall where the program has calculated when the aspheric mirror is a paraboloid.

I have used the test and found that the single reflection off the uncoated mirror gives much more light than testing by autocollimation. Looking directly at the pinhole does not bother me due to the greater light collecting area had the brightness of the return cone.

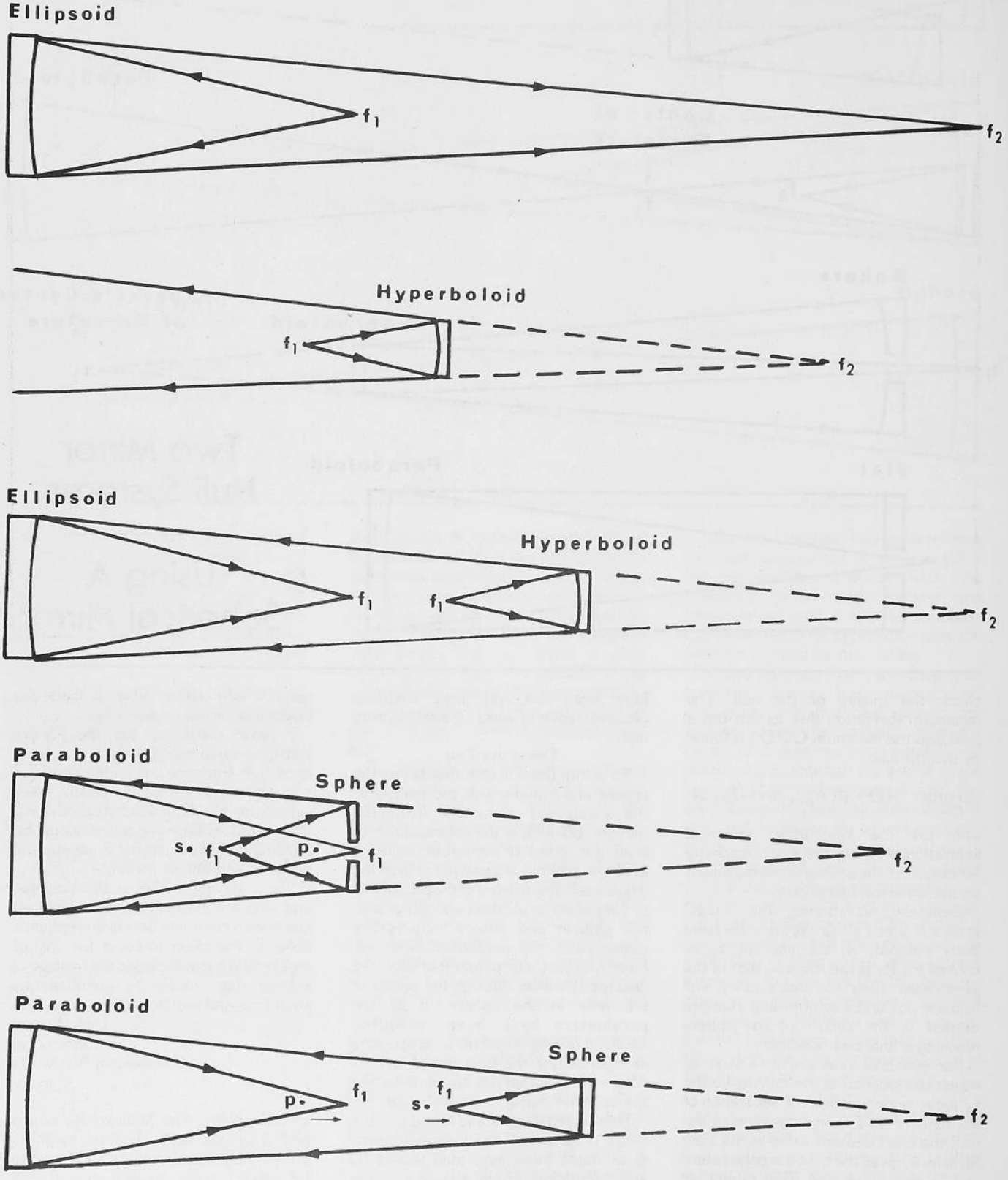
I have programs for the Texas Instruments 58 and 59 calculators, but I hope that someone will be interested in converting the formulae, which I will supply, for Hewlett-Packard calculators. Programs for home computers would be a valuable addition to the amateur lens designer and mirror maker.

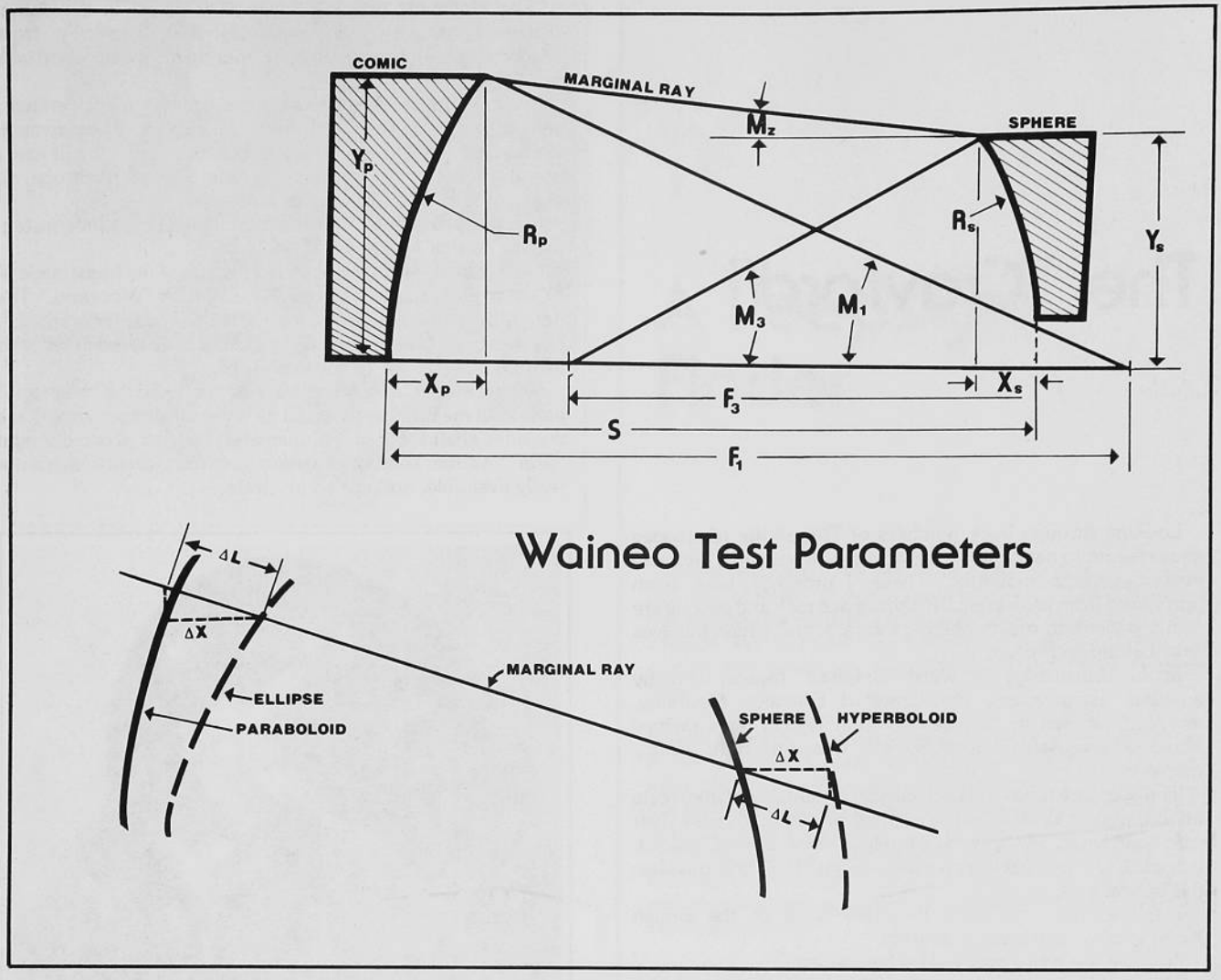
Those having a TI58 or 59 calculator and who are interested in this program can obtain complete details by sending a dollar to the writer to cover the cost of making the copy. Included is a method of solving the O.P.D. by simultaneous equations and integrating.

Tom Waineo
6 Perham St.
Chelmsford, MA 01824

Editor's Note: The Waineo Reflecting Null Test has been checked by three professional lens designers and found to be correct in its application and final performance. The analysis by Tom

The Waineo Test





Waineo applies a different criterion than the sophisticated professional lens design program, ACCOS V, using sagitta differences to balance the OPD (optical path differences) of the various light rays from different zones.

One professional designer commented on the test: "I feel Tom has a very interesting optical test, his treatment of which is quite thorough and speaks well of his analytical abilities. The test is deceptively simple. At first glance, one thinks one understands everything about it, but only really begins to appreciate the elegance of Tom's work after some deeper thought. His TI-59 program is especially interesting since it iterates to an excellent null in a very interesting way. The OPD determination is a good example of applying some optical theory from a book like Warren Smith's *Modern Optical Engineering* to an actual ATM problem.

"Basically the only drawback to the reflection null appears to be the rather large sphere it needs. This would seem to preclude the general use of a given sphere for testing a large family of paraboloids whose diameters would not be in the size region of the sphere. The Dall Test, of course, covers a large range of mirrors. The reflection null does seem to be insensitive to adjustment errors. Certainly those in axial positioning (errors in element positions along the optical axis) and a reasonable amount off-axis position errors do not degrade the null. A 2mm off-axis error on an f/4 mirror in the test still allows a ¼ wave null to be obtained."

Those in the business of making large numbers of mirrors for the amateur market might consider the Waineo Test. It assures near-perfect optics by using auxiliary optics of known and high quality. If good control over the radii of the paraboloids is maintained, it should be quite easy to make a Waineo Test jig to allow null testing of production quantities of mirrors.

The Waineo test will be most useful to amateur organizations who have classes or groups making mirrors, again however, only if they carefully control the radii of the mirrors being made. For the individual worker making one mirror, the effort of producing the spherical test mirror may not be justified.

Incidentally, clubs can help cut telescope building costs by standardizing other parts of designs so a minimum of different parts are needed in a telescope. Close control on the focal length not only permits a reflecting null arrangement to be practical, but standardizes other accessory parts: diagonals, spiders, cells, etc.

If the ideal arrangement is followed, that of having the F_1 focus fall just behind the spherical mirror, it should be obvious that the light source for the spherical mirrors will shine directly into the eye of the worker during the test. This is not only annoying but such stray light will reduce contrast and hence the ability to detect faint residual shadows. If possible, place a mask in front of the light source so it does not interfere with the light rays used in the test, but will shield the observer's eye.

R.E.C.

The "Crayford"

Looking through back numbers of TM, all the telescopes shown seem to have the conventional, or traditional, rack and pinion eyepiece mounting. These, I presume, have been purchased from professional makers since rack and pinions are rather difficult to make. Making the rack and pinion involves gear cutting technique.

In the British Isles the word "Crayford" means, to many amateur astronomers, the Crayford Eyepiece Mounting, invented, devised or designed by John Wall of the Crayford Manor House Astronomical Society, Crayford, Kent. Hence the name.

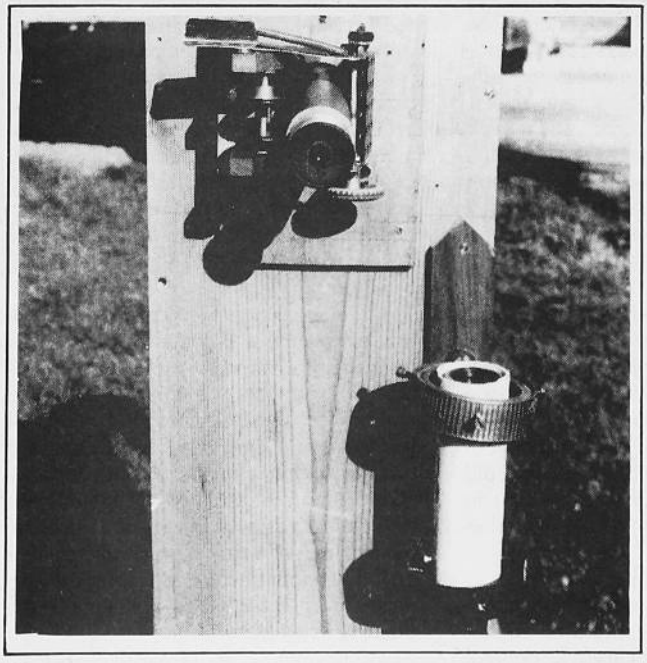
The eyepiece tube (and each eyepiece has its own tube) rests on four small ball-races, while a spring-pressurized cross-shaft with hand wheel on top holds it firmly in place. In the Crayford, there is NO slip or back lash or lost motion. It can only travel on the optical axis.

I quote from the 1971 February issue of the *British Astronomical Association Journal*:

"One of the tubes may hold a barlow lens"

"Complete absence of jamming, stickiness and side wobble"

"The rotation of shaft is necessarily smooth due to the absence of a rack and pinion"



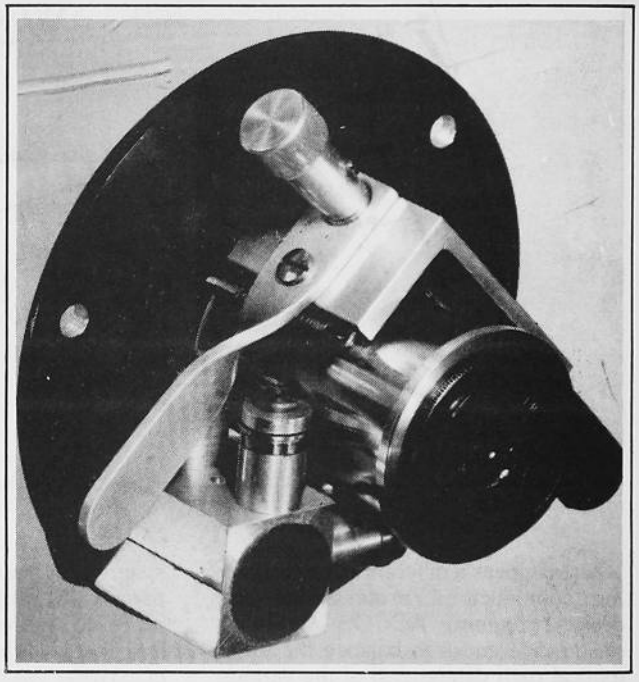
"The kinematic principle of stability inbuilt in the design enables it to work quite well even if built crudely, from 'Meccano' parts, for example, or entirely from hardwood with metal ball-races, of course!"

"The mounting has a pleasing appearance if made carefully, and has the complicated look of expensive equipment. However, it is neither expensive nor complicated, but just a useful ancillary that will not degrade a good telescope, or exasperate its user" — end of quote.

I have made several of these mountings. One is in constant use on Patrick Moore's 8.5" reflector.

On the back page of TM #6 is a picture of my homemade 6" reflector. This has a "Crayford" made from "Meccano." The tube moves on four rubber-tired wheels. The lever on the left lifts the drive shaft and eyepiece change is effected in seconds with no disturbance to the main tube.

When I made it about five years ago (in 1975) the "Meccano" parts cost me £1.25 — that is $2.50. I found by experience that if the drive shaft is about 3/16" diameter, it is just about the right "gear." A larger shaft gives a more rapid movement which is not really desirable, and not so accurate.



I think the picture of the one made in aluminium (made by my friend Eric Hole of Worthing, England) shows very plainly the construction and its simplicity, and needs little more description. However, here are some details of the ones I have made. A piece of aluminium bar 1" x 1" x 1.75" long, carries four small half-inch diameter ball-races mounted on stalks 5/8" high to resemble a V8 engine (or should I say a V4?).

My eyepiece tubes are one and half inches in diameter. If larger or smaller tubes are used, the ball-race "stalks" would have to be shorter or longer to obtain the correct bearing position. A short piece of channel section is hinged to the back plate, with either a compression spring on top or tension ones under. A finger behind the side lever and thumb on the lower pad easily releases the pressure bar for eyepiece change. Anything else, I feel, would only complicate this beautiful simplicity.

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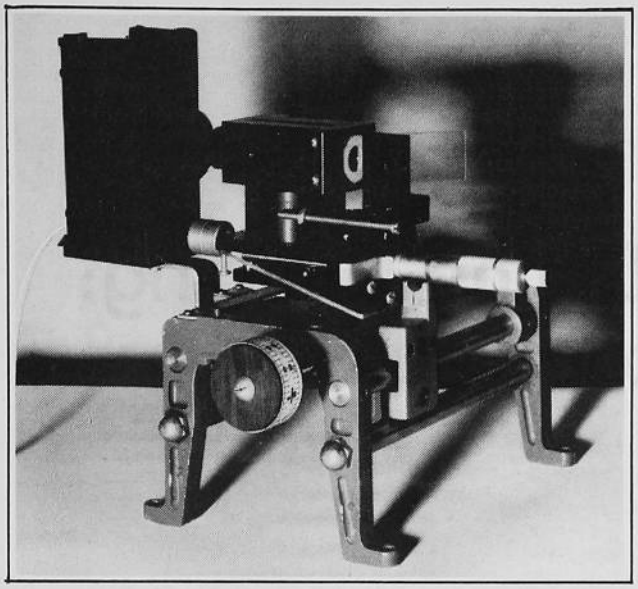
Selsey, Chichester
Sussex, P020 OAU
England



Ronchi Test with a Null Lens

Here is a different way to use an already good optical test that I came upon while checking a friend's mirror. Set up a simple Dall null test for your mirror, but instead of using a knife edge, use an ordinary Ronchi screen. If the mirror is correct, straight bands will be seen, if not, continue figuring until they are.

I use this test with a 100-watt projector light source and a beamsplitter type setup (see *Sky & Telescope*, June '77) for on axis testing of fast mirrors. Fast mirrors are troublesome to null test without a beamsplitter, due to the separation of the eye and the test unit which causes astigmatism. There is also the problem of getting enough light through a red filter and pinhole without burning your face.

The beamsplitter, a microscope slide, can be tested for flatness by placing it on an old binocular prism and viewing it under fluorescent light to see if the bands are fairly straight. Another method might be to test it against a spherical mirror which has been previously checked out in a knife-edge test.

A word of caution should be given in regard to finding the exact focal length of a plano convex null lens. The lens must be stopped down to about f/10 for an accurate measurement (see S&T, Sept. '76). If a clear red filter is placed in front of the lens, and the image of the sun is projected onto a dark surface, it will be easier to view. If the lens has not been stopped down, measurement inaccuracies of up 0.1 inch may be encountered.

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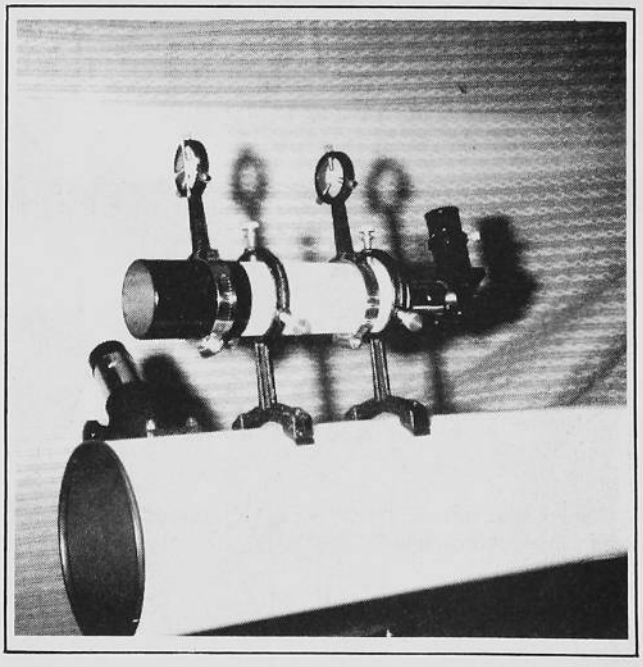
A Peepsight Finder

Many beginning TMs like myself may be frustrated by the difficulty of finding a star through a right angle finder. I solved this problem by using an extra set of finder rings as a boresight mounted on the finder. The finder rings were attached to hose clamps and the clamps were tightened onto the main finder tube.

If the eye is placed at the correct distance and position behind the rings, the rings will appear as two concentric circles. A star can now be easily centered in the rings and after some initial alignment will be within the field of the main finder. Seeing the rings on dark nights is not a problem since they can be illuminated by a flashlight.

If you consider that there is at least one commercially available unit that serves the same purpose but costs about $50 and requires batteries, the simplicity of the above method becomes obvious.

Gary Papazian
Hopkinton, Mass.



Mirror Curvature During Grinding: A Mathematical Treatment

To begin with, we need a formula for the focal length of the mirror, provided we know its radius, a, and its depth at center below the rim, h.

Comparing the formulae for the volume of one-base spherical segments:

$$V = \tfrac{1}{3}\pi h^2 (3R - h) = \pi h/6 \ (3a^2 + h^2)$$

We see that R (the sphere's radius) appears only once in one term of one of the equations and that it is the first power.

Multiplying through we obtain:

$$\pi h^2 R - \frac{\pi h^3}{3} = \frac{\pi h a^2}{2} + \frac{\pi h^3}{6}$$

so:

$$\pi h^2 R = \frac{\pi h a^2}{2} + \frac{3\pi h^3}{6}$$

$$= \frac{\pi h a^2}{2} + \frac{\pi h^3}{2}$$

Dividing through by πh^2:

$$R = a^2/2h + h/2$$

Placing the right-hand fractions over the same denominator:

$$R = \frac{2a^2 + hh^2}{4h} = \frac{a^2 + h^2}{2h}$$

R is twice the focal length so:

$$fl. = \frac{a^2 + h^2}{4h} = \frac{a^2}{4h} + \frac{h}{4}$$

The focal length will be changing with respect to h, which itself will be changing with time:

$$\frac{\partial F}{\partial t} = \frac{dF}{dh}\frac{dh}{dt}$$

This is the well-known trick of introducing a dummy variable.

$$\frac{\partial f}{\partial h} = \frac{-a^2}{4h^2} + \frac{1}{4}$$

$\partial f/\partial t$ has a measureable value. In my own TM work, it is approximately 0.12 mm/hour.

So:

$$\partial f/\partial t = \frac{\partial F}{\partial h}\frac{\partial h}{\partial t} = \left(\frac{-a^2}{4h} + \frac{1}{4}\right) 0.12 \frac{mm}{hr}$$

$$\cong \frac{1}{33}\left(\frac{-a^2}{h^2} + 1\right) mm/hr$$

Note that when a=h, progress in reducing the focal length stops. This cessation of deepening is because, until that point, the rim of the mirror has been the edge of the one-base segments for a succession of ever-smaller spheres. But the smallest sphere that can have a base, in its segment, equal to the diameter of the mirror is a sphere just the size of the mirror.

So, retaining a spherical form, for the surface to have f < h/2, when a = h, would require a sphere smaller than the diameter of the mirror. That would require glass to be added uniformly over the entire ground-out surface, which, at a=h, is a hemispherical cavity. Hence, acording to the above treatment, once one has a hemispherical cavity, there will be no further deepening, even if one keeps on grinding till Doomsday.

I found the constant dh/dt using #40 Unasil grit on lime glass. Any finer grit will produce a smaller value for dh/dt, as will the use of a harder glass, such as Pyrex. Still, once one has a value for dh/dt, using a given grade of grit and a certain glass, one may predict how much progress one will make in a grinding session. Ideally, and as I have treated it here, the edge of the glass does not wear down at all. In reality, it does wear, typically 0.07 to 0.08 mm/ hour.

Note that the function is behaving sensibly. That is, df/dt is always negative, and decreases with time. Physically, one may pull the focal length in from infinity to 100 meters or so in an hour's work — but the next 96 meters will take a month. Further, note that this equation comes out right dimensionally, that is, multiplying it by the length of a grinding session will give an answer in mm^1.

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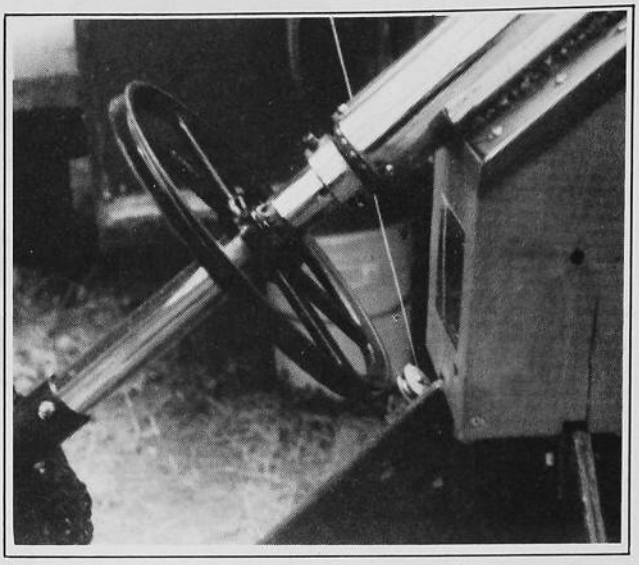
Author was inspired to do this analysis because he is building a pair of 16" aperture binoculars.

A Sand-Powered Drive



Bruce C. Smith of Salt Lake City, Utah won an award at the 1979 Riverside Conference for his weight driven clock drive. Smith's drive involves the same principle as the hourglass, where a quantity of sand funnels through a valve. In the drive, however, a weight resting on the sand slowly drops, pulling a wire which is attached to the polar axis.

For the nomadic astronomer who leaves the lights of the city behind for dark skies, the old concept of a weight drive has many advantages. First, it does not depend on a source of electricity. Second, it is inexpensive to build compared to the purchase price of a conventional drive. Third, it doesn't require a Ph.D. in physics to figure out all the gear ratios, etc.

During the past five years, Bruce has experimented with sand as a basic component of a weight drive system. If a heavy weight is placed on top of a container of sand, and the sand allowed to trickle out from under the weight, a very even and predictable settling of the sand occurs.

In this case the container for the sand is a 6″ diameter by 19″ length of aluminum stove pipe. At the bottom is soldered an ordinary 6″ diameter metal funnel.

A steam valve attached to the funnel allows control of the rate of flow of the sand. Bruce has found that the valve should be a steam valve rather than a water valve, as the shut-off mechanisms differ. A steam valve uses a rubber ball, but a water valve uses a mechanically turned plate. Sand gets hung up in a water valve mechanism, but flows around the ball in a steam valve. If the sand hangs up in the valve, it will bunch up and stop flowing, thus stopping the drive.

On top of the sand cylinder is a solid lead weight cast in a cardboard tube, to be easily slid through the stove pipe. Bruce uses a 50 pound weight to drive his 8″ f/8 Newtonian. Less weight is needed for smaller scopes, more for larger. The best source for lead is a scrap metal dealer or garage. As Bruce says, buying it at a hardware store will cost "an arm and a leg".

The next major drive component is the drive wheel. This is a 12″ diameter cast iron pulley wheel available in a wide variety of shaft diameters from industrial supply shops.

To connect the sand weight and the drive wheel, #24 diameter zinc plated wire is recommended. It is strong enough to take the strains, and has the right elasticity to run smoothly through the pulley wheels.

The only other components are an eye-bolt, an "S" hook and a 4″ or 6″ turnbuckle.

Bruce claims the fine grained sand of Utah is the ultimate for this drive, but suggests that rather than going all that way to get sand, use whatever is locally available the size of 180 or 220 abrasive. The sand should be kept clean and dry by storing it in a plastic container when not in use.

Drive speed adjustments for the Smith Sand Drive are made in two ways: Coarse adjustment is made by opening or closing the steam valve to slow or speed the rate of sand/weight fall; fine adjustments are made by using the turnbuckle. Bruce claims the drive will give him a 4 second unguided exposure time. From an observational standpoint, the drive motion is very smooth. By varying the number of wraps of wire around the drive wheel, and using a full cylinder of sand, drive times of up to three hours can be obtained.

The drive rate does not change with temperature. I had an opportunity to use Bruce's sand drive scope at Wolf Point, Montana during ECLIPSE '79, and found it working extremely well in the Montana cold.

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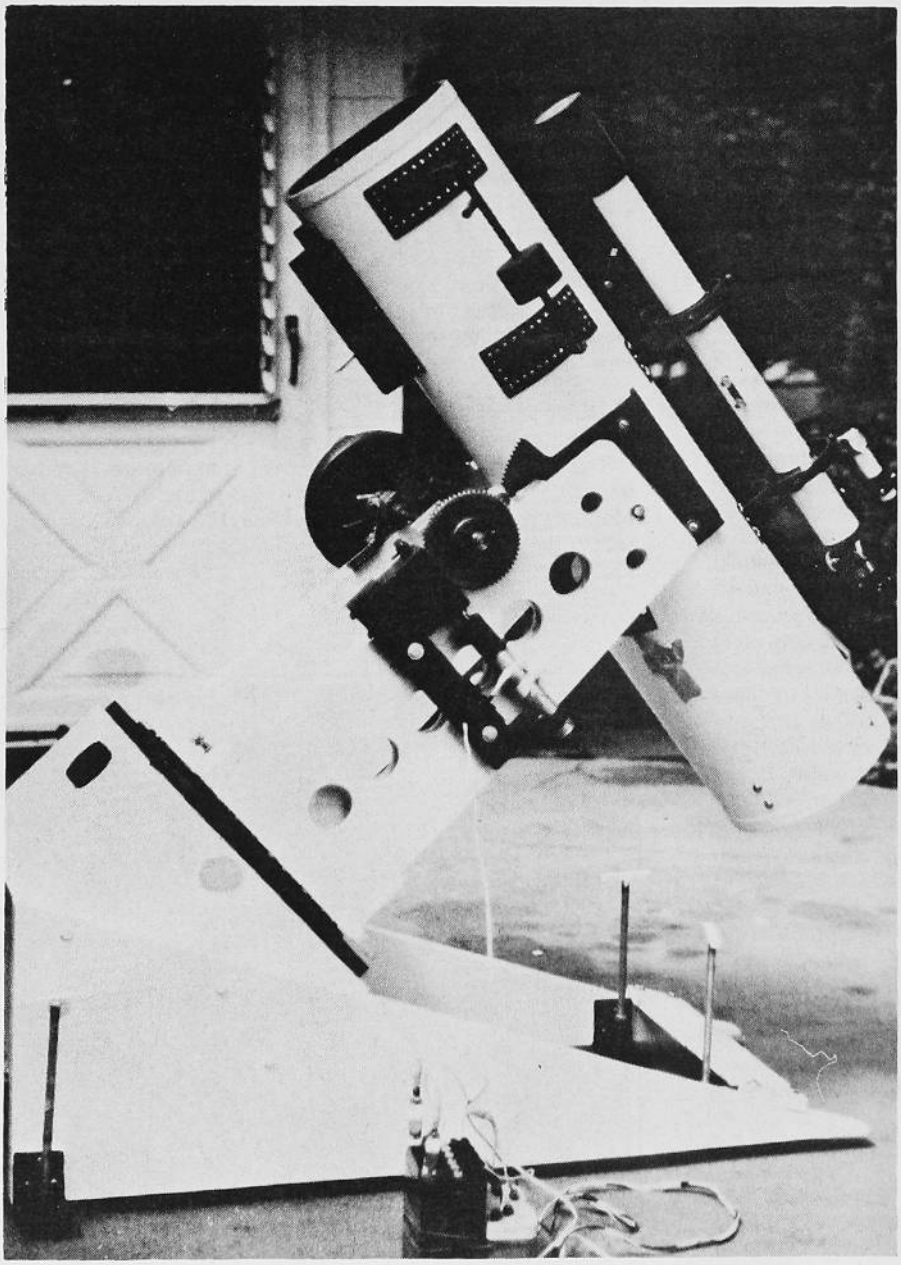
An 8" Reflector on a Homebuilt Mounting



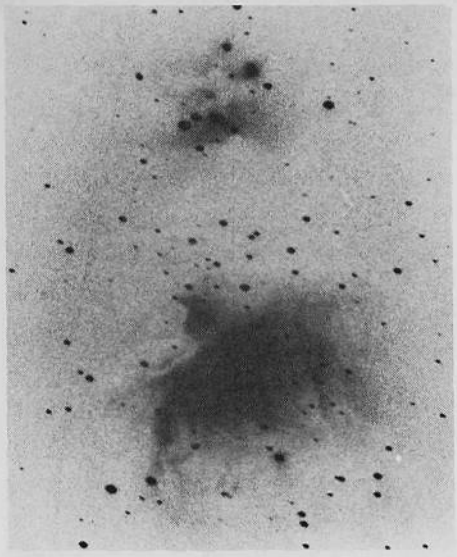
Over the last several years, I have been improving my 8" reflecting telescope for deep-sky astrophotography. While it still has a few bugs in it, I am pleased with its performance. Recently I added a 4½" guide telescope (for easier deep-sky guiding) and removeable wheels to make the telescope easier to set up around my house and yard.

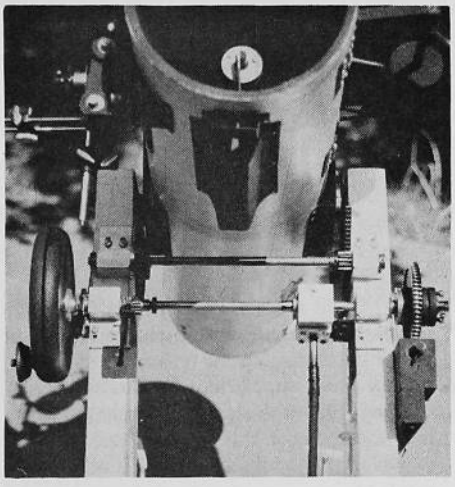
To the original 8-inch reflector Newtonian telescope, I have added a new mounting and a wide range of accessories. The mounting consists of a box base supported by two triangular legs; a massive fork, a unique hand-crank system for tracking. I also added the guide telescopes, which ride on the back of the main telescope and are mounted in rings, and improved the shaft and added jacks for the polar axis.

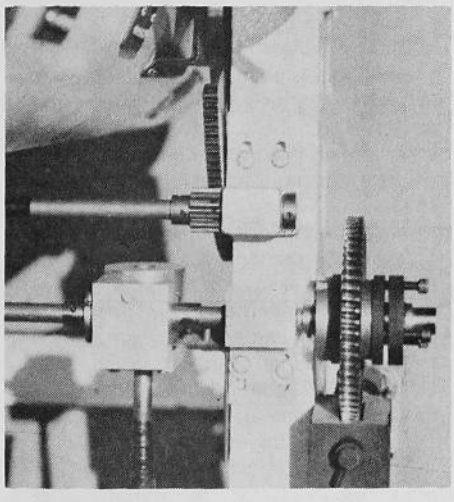
A large percentage of the telescope is made out of wood. Although the entire instrument weighs over 120 pounds, it disassembles into three sections: the tube, the fork, and the base. For quick knockdown, only one bolt attaches the box to the fork, and two nuts hold the telescope in place between the fork arms. The square box, on a 41 degree angle, is about 3 inches off the ground.

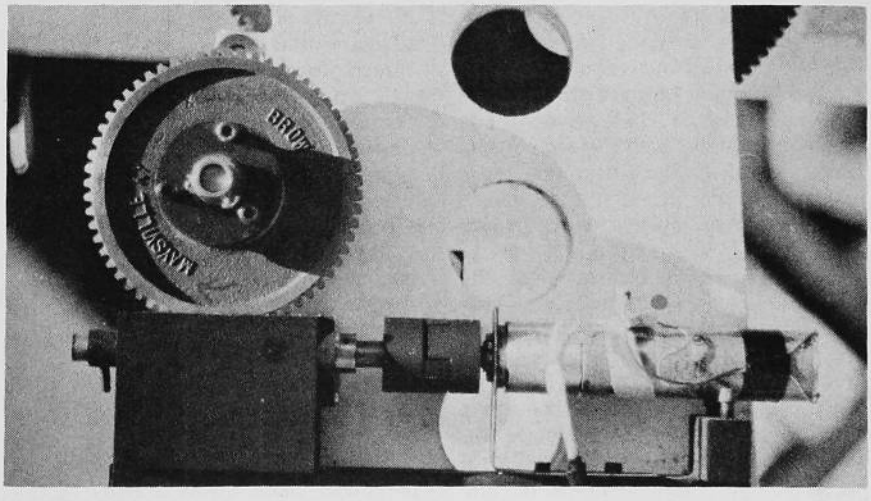
The fork is both motor driven and hand driven. It rotates when one cranks the outer handle. Opposite the handle, a surplus 12-volt motor 1.25" x 6" drives a 60-tooth worm which drives the telescope. I regulate the motor's speed with a 25-ohm rheostat in normal operation, and for higher speeds, I use a 24-volt battery with a 35-ohms rheostat.

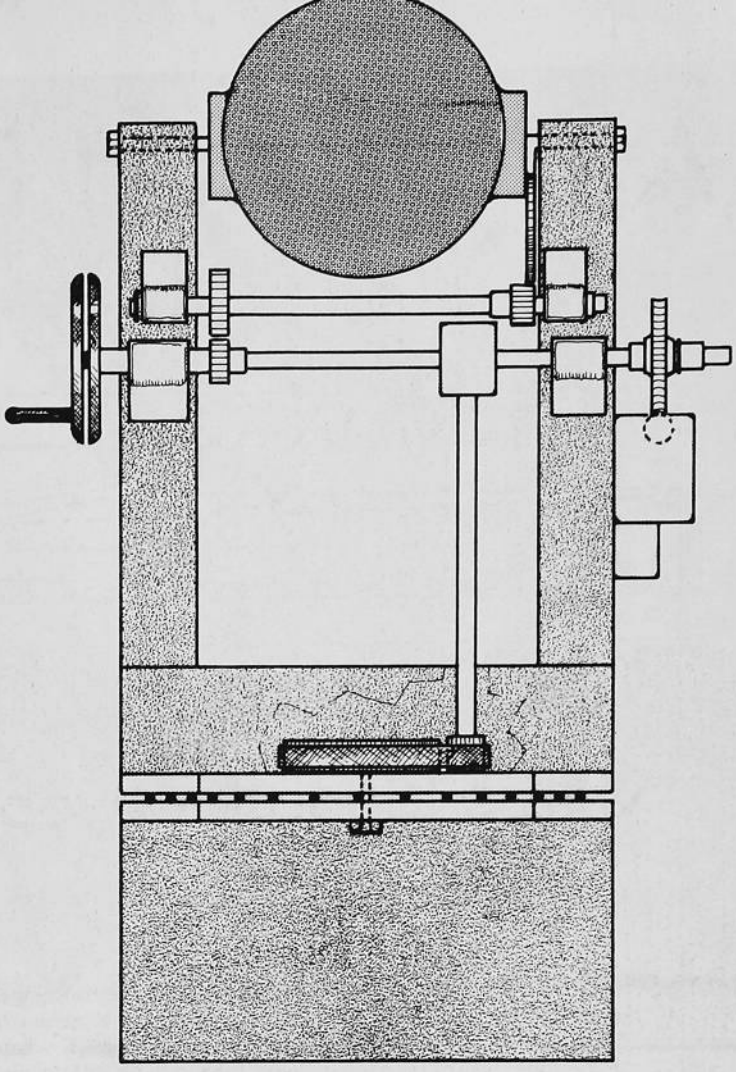
The motor is runs continuously. A bakelite clutch plate (with pressure applied to it with three screws) presses against gear and transmits the motion of the gear to the shaft. Although pressure is being applied to the shaft causing it to tighten, one can still override it manually











and turn the shaft while the gear is in motion.

To rotate the fork one full turn, the handle or the 60-tooth gear must make 192 turns. One handle turn therefore equals 1.875 degrees. For the worm box to drive the 60-tooth gear one revolution, the worm box would have to be turned 60 times. One turn on the worm box is 0.0312 degrees. The motor thus requires 8 seconds to complete one revolution, or 7.5 rpm. The motion of the shaft is reduced by a gearbox and transmitted to a small pulley wheel. This turns a Vee-belt that wraps around a stationary pulley wheel.

Turning the other handle moves the outer shaft, which causes this motion to move the telescope in declination. I find it handy to have both axes under control from a single pair of adjacent handwheels.

Richard Andreassen
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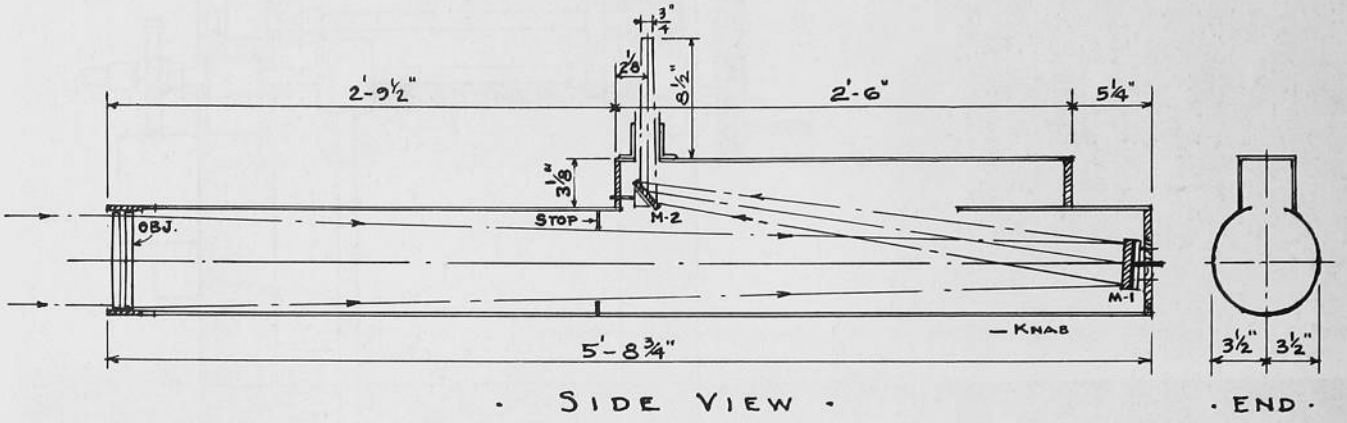
Westbury, CT 11590

■

A 6" Folded Refractor



with a binocular eyepiece holder

In 1977 we moved to the Ozark Mountains in Arkansas. I therefore had to dismantle the 6" Polar Refractor which had been built into the south wall of my house (see *Sky & Telescope*, July 1970, page 46). Since the fabrication of the lens was described in that article, I will not repeat it here.

In the new location, I found that I needed a roll-out semi-portable equatorial mount of good stability, so I decided to fold the f/18 beam of my fine 6" Baker objective with two high quality flats to make the instrument more manageable. For the first reflection, a 3.12" diameter 1/20-wave quartz flat was used, and for the second, a 1/20 wave 2" minor axis pyrex elliptical near the eyepiece. I could have conserved a little light by using enhanced coatings but decided on the standard aluminizing to save time and expense.

The flats were placed to provide a handy position of the eyepiece — without regard to a possible tilted focal plane. To date, I have not detected any difference in focus from edge to edge of the field of view, even though there is a calculated difference of approximately ⅛" between the lengths of the top and bottom light paths due to the tilts of the flats.

For the polar axle, I cannibalized a little grinding turntable for a 1" shaft with 5" diameter cast iron disk on upper end and two self-aligning oilite bushings. The assembly proved quite sufficient to support the 5'6" long, 7" diameter aluminum tube with its mahogany fork, circles, and indicator lights.

I made an R.A. drive sector from ¾" particle board. The gear teeth are made of wood putty pressed when still workable into the ⅝" diameter by an 11 thread per inch shaft directly coupled to a ½ r.p.m. Hurst synchronous motor. Surprisingly, the assembled drive is perfectly smooth, and the 34° sector will permit following for over two hours before the cut-off switch is actuated and the sector is reset.

The right ascension slow-motion is accomplished by moving the entire base containing the drive motor and its threaded worm shaft to right or left by means of a 1/4-20 bolt turning in a tapped hole in the base strap.

The declination slow-motion is a simple sector type.

The base of the telescope is a wood pyramidal stand made of two-by-fours and ½" plywood glued and screwed together. The rear wheels are discarded 8" cast iron rubber-tired push mower wheels and the front are two 3" rubber-tired casters. Near each caster is a ⅝" threaded rod screw-down anchor.

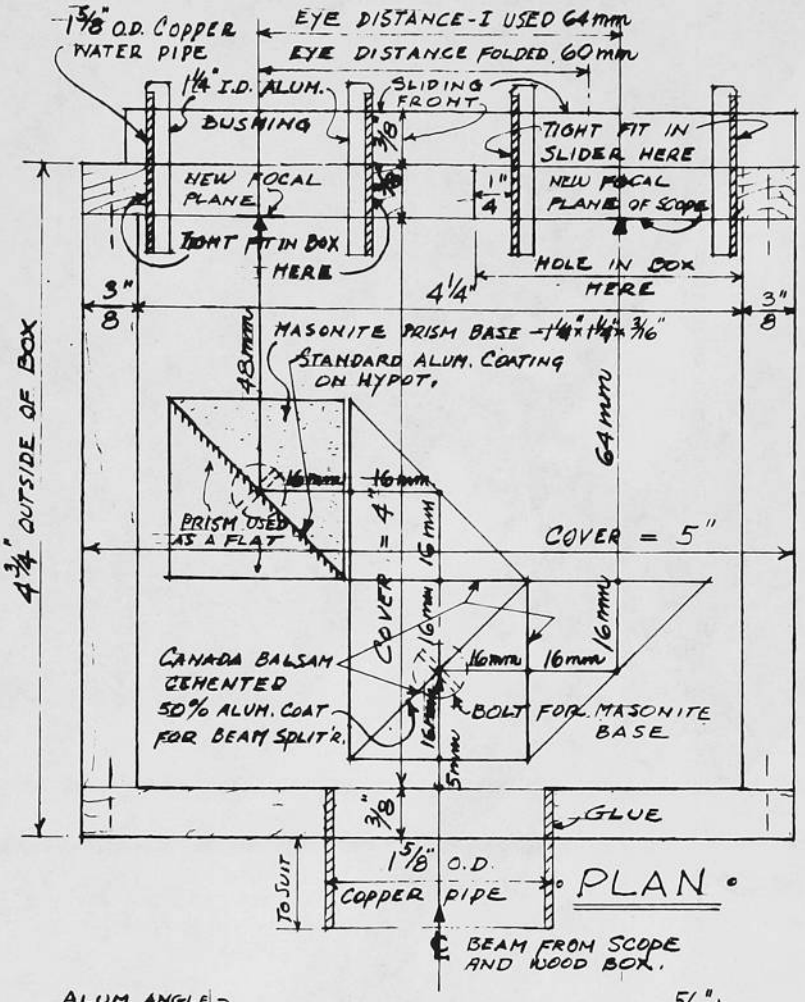
To make set-up easier, after aligning it initially and carefully testing for drift, I drilled two small holes in the concrete driveway. Screw-down anchor pins fall into these holes, so the telescope can be repositioned in perfect alignment for viewing each time it's rolled out. I marked the small holes in the drive with a 3" spot of white paint for easy identification at night.

For observing convenience, this telescope is ideal — this you will see by examining the pictures closely. Current for such features as the illuminated circles, map shelf, and Polaris line-up lights is supplied by an ordinary bell transformer mounted in the back of the shelf.

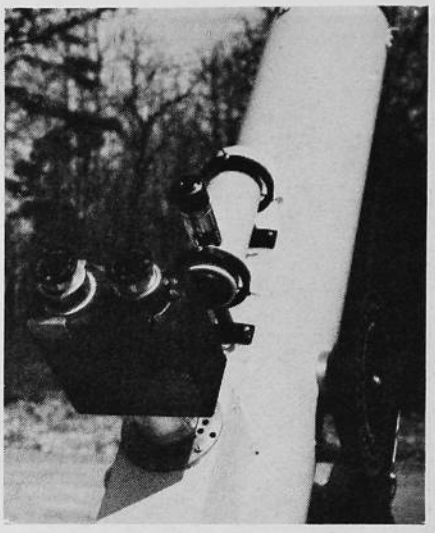
Notes on the prism beamsplitter: It is difficult to cement two right-angled prisms together to form the beam splitter assembly. Any rotation of the two prisms will cause trouble, and such a rotation happens easily. Also, the beamsplitter coating on the one prism face (hypotenuse) is "special order" chromium coating and quite expensive to have done for just one. Aluminum is a poor material for the beamsplitter coating. Chromium does not introduce color as does aluminum. In the long run it is better to purchase the prism already assembled as the cost will probably be about the same as having a special unit constructed.

The prisms are equivalent to a block of glass equal to the distance traveled in the glass by the light (and the thicker the

• BINOCULAR EYEPIECE HOLDER •



PRISMS ARE 32mm X 32mm FACE RIGHT ANGLE OF GOOD QUALITY. WOOD IS SOLID MAHOGANY (NOT PLYWOOD).



glass the more aberrations). In a converging light beam, a thick block of glass overcorrects longitudinal spherical, chromatic, and astigmatism, and undercorrects transverse coma, distortion, and lateral color. (Longitudinal aberrations are along the axis of the lens system toward and away from the objective, while transverse aberrations are at right angles to the longitudinal axis.) These aberrations are serious for short focus telescopes, but more forgiving on long focus instruments so Mr. Knab has not been bothered by them with his observing.

For the best results, the focal lengths of two eyepieces used in a binocular assembly should be identical. Normal manufacturing tolerances result in differences of magnification that may either hinder or make impossible proper fusion of the two images. Although ideally the eyepieces should be selected for matched focal lengths, in many amateur-built units satisfactory results have been obtained with stock items. However, if any trouble is found in such an assembly, it is a good idea to try to check the two eyepieces for differences in their focal lengths.

I can view most objects comfortably seated on an ordinary 22" high stool. For lunar viewing, I usually use a homemade binocular eyepiece holder. It is difficult to describe the unforgettable beauty and depth of the Moon when viewed with a pair of 28 mm ortho oculars in this unit. Even Saturn's rings seem to have a depth and feeling of actually encircling the sphere.

After several months of use, I find the telescope very convenient to use. The optics perform beautifully, the eyepiece position is comfortable for more objects, and the mount is easy to roll out of the garage to its viewing position.

Oscar R. Knab
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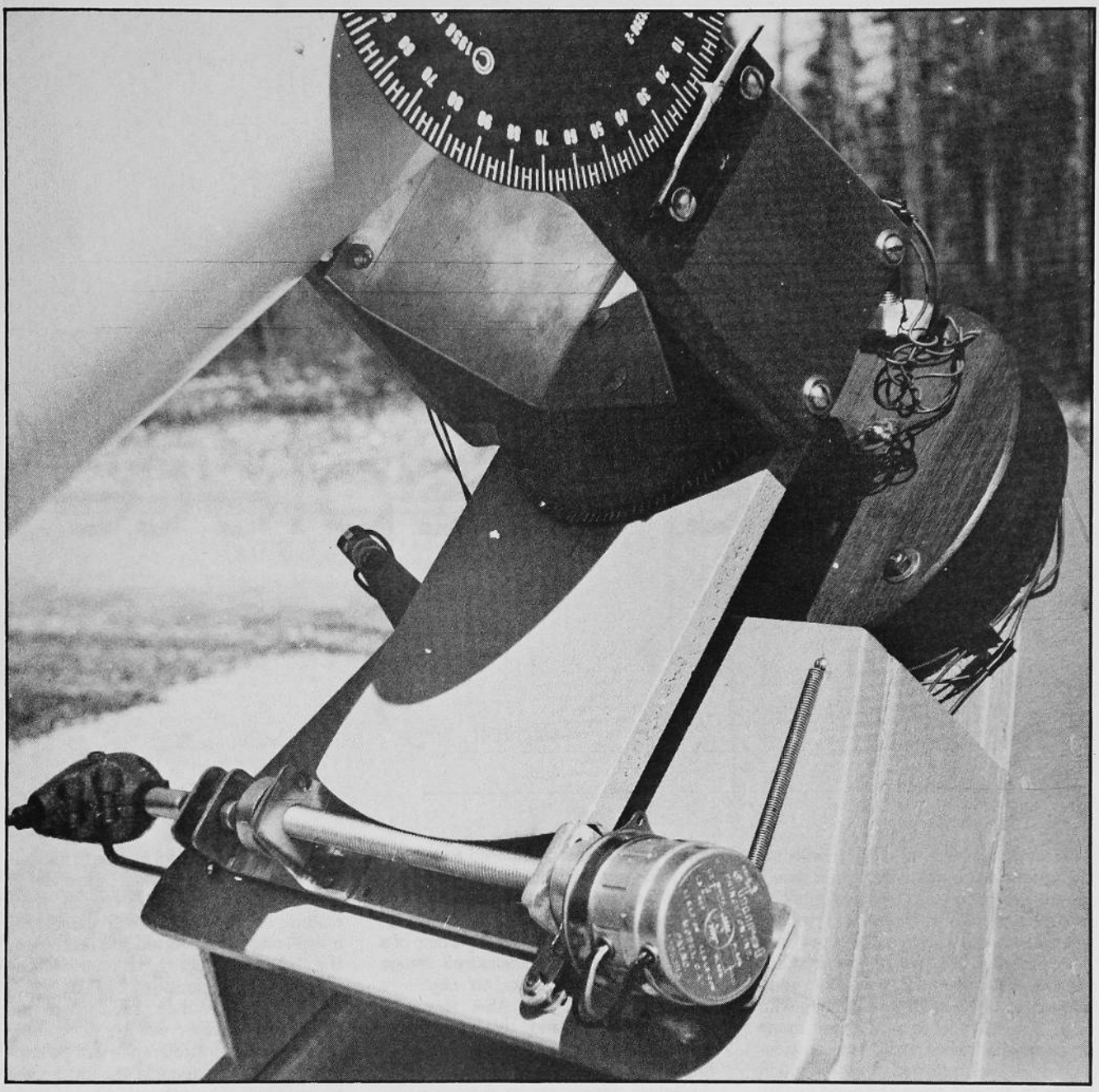
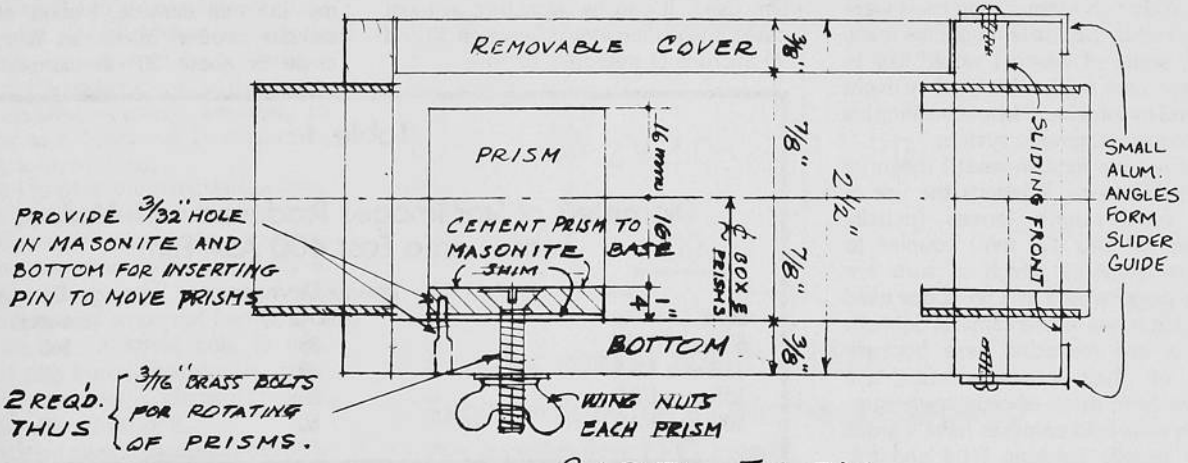
Holiday Island, AR 72632




REMOVABLE COVER
3/8"
PRISM
16 mm
7/8"
2 1/2"
SLIDING FRONT
SMALL ALUM. ANGLES FORM SLIDER GUIDE
PROVIDE 3/32" HOLE IN MASONITE AND BOTTOM FOR INSERTING PIN TO MOVE PRISMS
CEMENT PRISM TO MASONITE BASE
SHIM
16
℄ BOX & PRISMS
7/8"
1/4"
BOTTOM
3/8"
2 REQ'D. THUS
3/16" BRASS BOLTS FOR ROTATING OF PRISMS.
WING NUTS EACH PRISM

· SIDE ELEV. ·

A Simple, Practical Guide Eyepiece

When I finished my 8″ f/7 reflector about four years ago, I thought it would be easy to produce many breathtaking astrophotos with it. However, it turned out that due to many compromises I had been forced to make during the building of the instrument, it was not good enough to allow error-free guiding with such a long focal length. After many unsuccessful trials, I finally stuck to wide-field work which turned out to be much easier to do, and produced good quality shots. Although many of my trials were unsuccessful, they have taught me many things, some of which I would like to share with the reader. I hope they might be useful to somebody who is building his own astrophotography system.

First, let me explain what I mean by "wide-field" work. It means the use of short focal length lenses (usually between 50 and 300 mm) coupled to ordinary cameras which in turn are usually piggybacked to a telescope used as a guide scope for the camera. Schmidt cameras are excluded here because many of their characteristics are different from those of ordinary lenses.

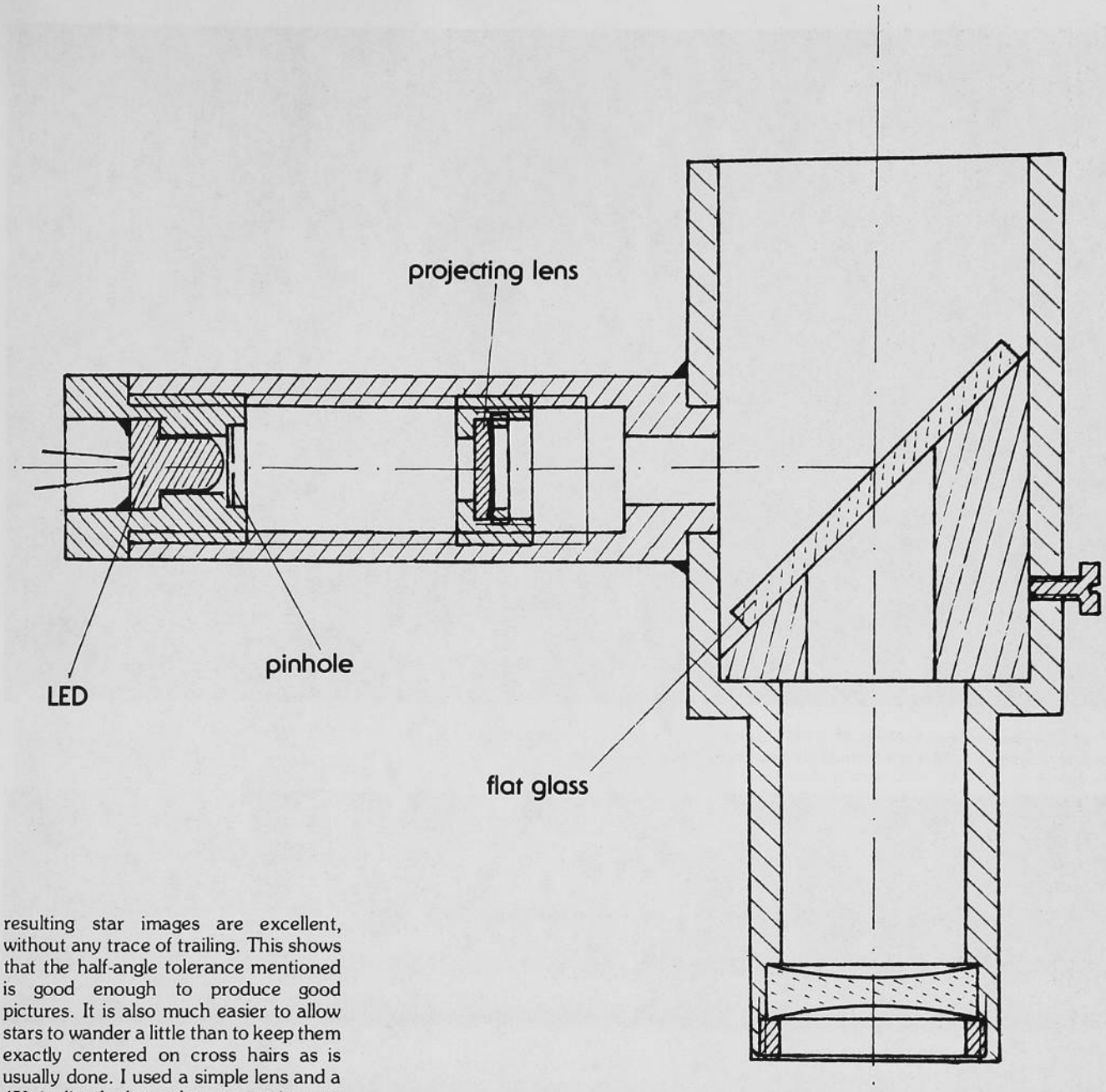
Such wide-field cameras have a small f/ratio, usually between f/1.4 and f/4, which is quite fast compared to normal f/8 Newtonians. The fastest of these lenses are indeed faster than Schmidt cameras — but have much worse image quality than a Schmidt. With the help of a microscope, I have measured image diameters of faint stars on negatives taken on a fast 400 ASA film with different lenses, and the results are presented in Table 1. Slow fine-grain films showed up to 25% smaller diameters depending on the particular film used. It can be seen that in most cases image diameter is between 30 and 40 microns (1 micron = 10^{-6}m).

We can use this information to find out how accurate guiding must be in order to produce round star images. In the third column of Table 1, the linear diameter of a star image is converted into an angle in the sky, to which this diameter corresponds. If, during guiding, all errors are kept smaller than, say, half of this angle, star images will be acceptably round. And if this tolerance can be kept at a quarter of that angle, the images will be excellent. For instance, when I guide my 135 mm camera, I allow stars to wander around inside an illuminated circle of about 20″ in diameter. The

Table 1

Diameters of Star Images Produced with Various Lenses on a Fast 400 ASA Film

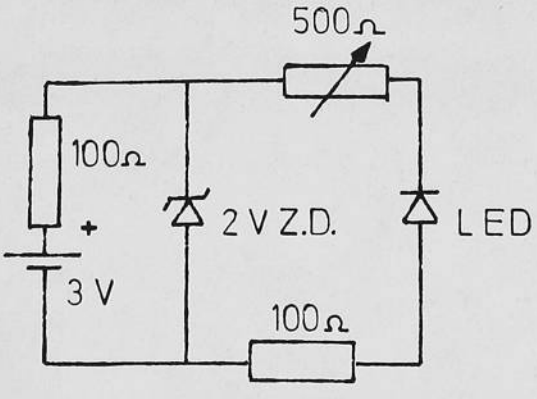
Lens	Image Diameter (microns)	Image Diameter (arc-secs)
50 mm f/1.8	35	145
135 mm f/1.8	40	60
135 mm f/2.8	30	45
300 mm f/4.5	60	40



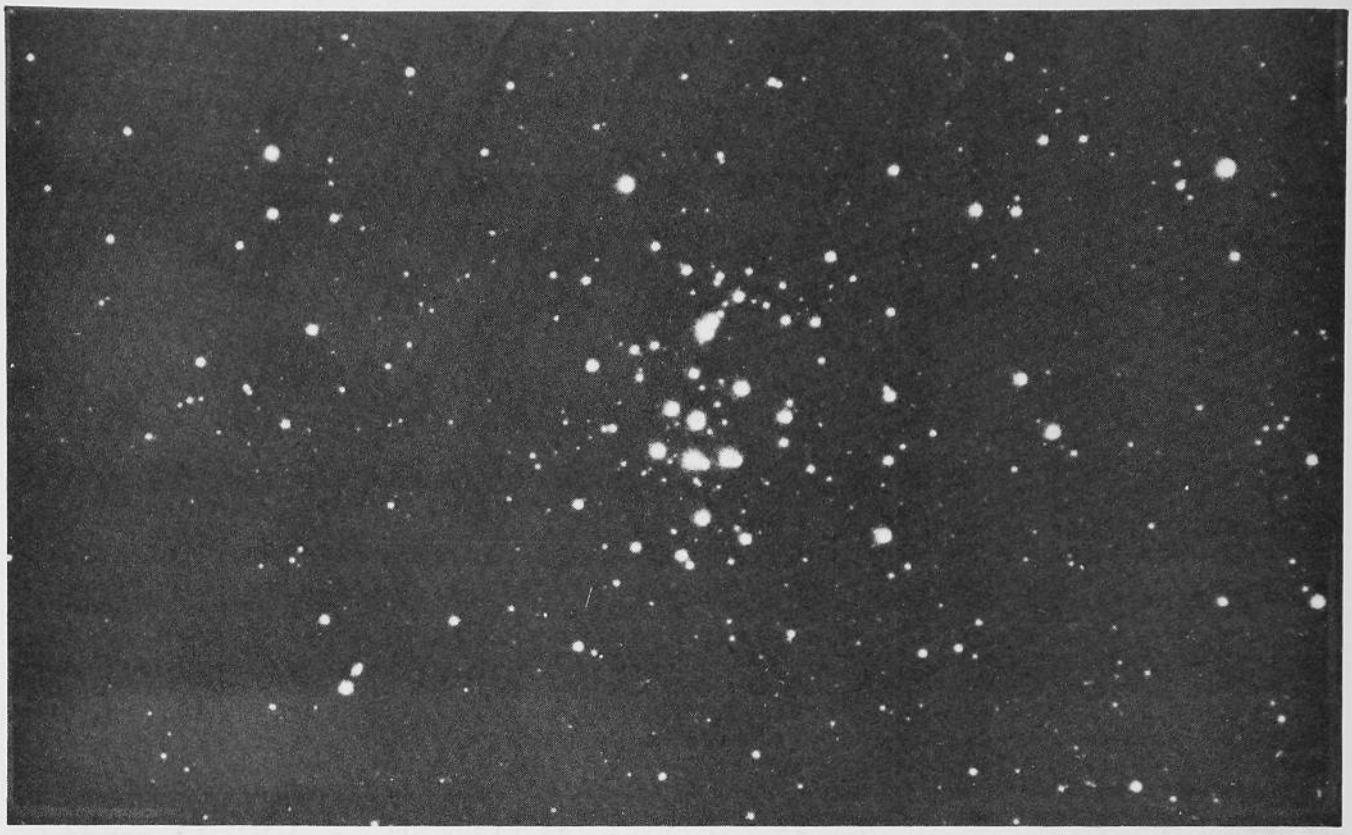
resulting star images are excellent, without any trace of trailing. This shows that the half-angle tolerance mentioned is good enough to produce good pictures. It is also much easier to allow stars to wander a little than to keep them exactly centered on cross hairs as is usually done. I used a simple lens and a 45° inclined glass plate to project an image of the circle to the guide eyepiece focal plane. The circle is the image of a pinhole placed in front of a light-emitting diode (LED). The brightness of the circle can easily be adjusted by a variable resistor in the power circuit of the diode. As this guiding eyepiece was easy to make and as it works well, I will describe it in a little more detail.

I started from an ordinary Barlow lens. Inside its tube, I put a piece of plastic pipe cut at 45° on which a piece of microscope slide glass was glued. This assembly is held in place by a small screw and can easily be removed to permit normal use of the Barlow. A small hole (5 mm diameter) was bored opposite the plate glass and the projection elements holder was soldered in front of it.

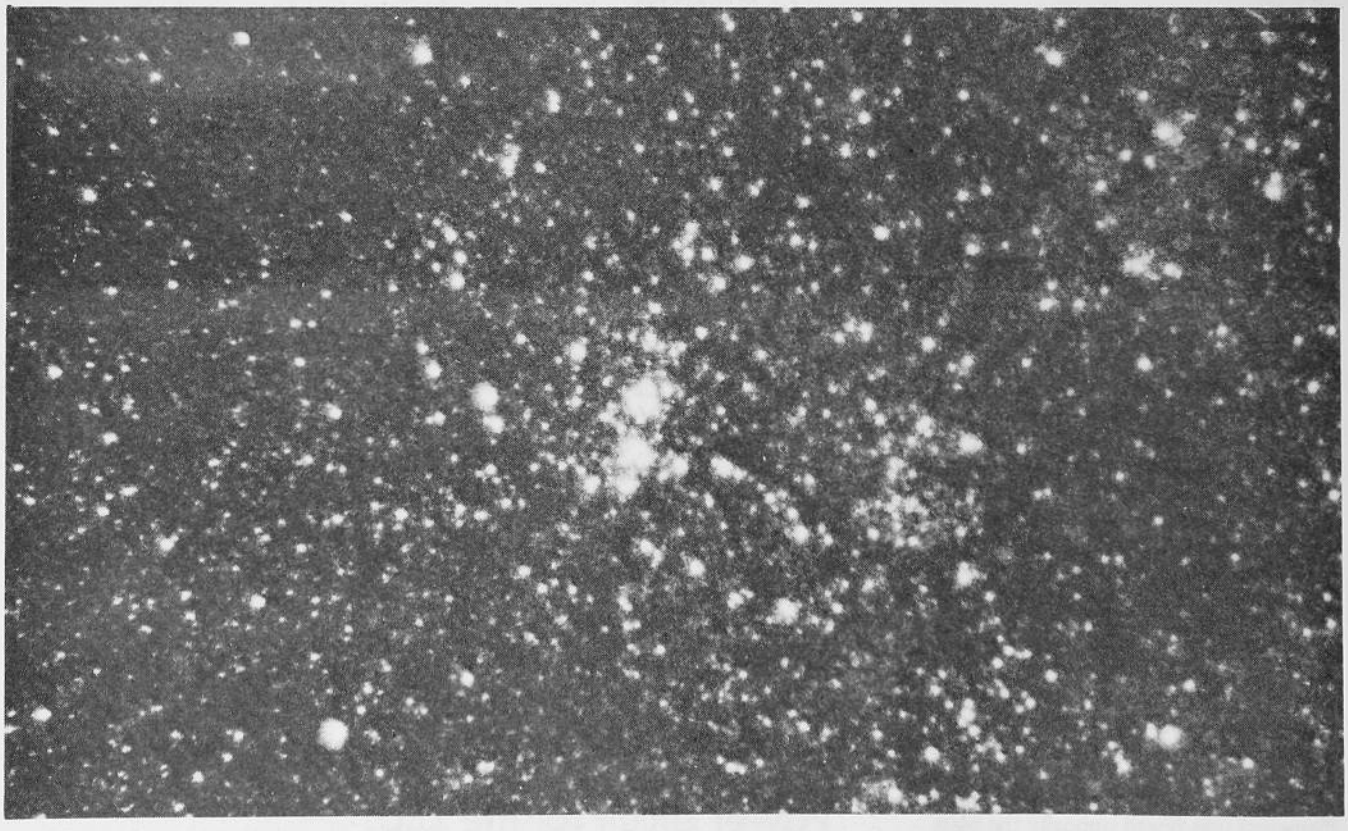
The inclined glass transmits about 80% of the light coming from the Barlow and



Power circuit for the LED.
Exact values of its elements depend on particular LED used.



M-44 Praesepe photographed with a 2.8/135 mm lens. This 12 minute exposure was taken on ORWO NP-27 (400 ASA) film. The reproduction is a 9x magnified portion of the original plate.



The enormous richness of the star field around Double cluster in Perseus is well presented on this 10 minute exposure on KB-21 (100 ASA) film and 1.8/50 mm lens.

The big luminuous sphere is Sirius. At the time of taking the picture some icy crystals were present in the upper atmosphere; they diffused the brightest star's light and produced this unusual picture. The cluster near the bottom of the picture is M-41. I used NP-27 film and a 7.5 minute exposure with a 2.8/135 mm lens.

reflects about 10% of the light coming from the projection system. It makes it possible to see simultaneously both the star field and the image of the circle through the eyepiece. The LED and lens mount required some machine work, but it was easy and I finished it in an hour's time. I used a simple lens and adjusted distances so it projects a sharp image of the pinhole into the eyepiece image plane. Any lens with a focal length between 10 and 20 mm will do the job. To allow small adjustments (in order to bring the sharp image of the pinhole to the eyepiece focal plane), the lens is mounted in a cell which can be screwed in or out in the tube that holds the whole assembly on the Barlow body. Note that the magnification of the pinhole image is the same as the ratio of the distance from the lens to the eyepiece focal plane to the distance between pinhole and lens.

The LED itself is mounted in a similar way and fixed to the end of the mounting tube. A pinhole made with a sharp needle in a piece of aluminum foil is glued in front of the LED. A little experimenting with various pinhole sizes was necessary to get the right size of the illuminated circle. Note that the apparent diameter of the circle is equal to the ratio of the size of the circle's diameter to the effective focal length of telescope and Barlow combination. The change of eyepiece alters the magnification of the circle and the star field to the same extent, but the apparent diameter of the circle measured on the sky remains the same.

When you look through the eyepiece with the LED glowing, you see two circles (images of the pinhole) in the middle of the field of view. The second circle is due to light reflected from the back side of the 45° glass plate used, but it does no harm. The distance between the two circles can be varied if necessary by varying the thickness of the inclined glass plate. A thicker plate will give a greater distance.

The advantage of those circles is that they are not opaque. In fact, one does the guiding in such a way that the guide star always stays inside that glowing circle, which is much easier to achieve than to keep the star centered on cross hairs. The drawback is that the guide star should be rather bright (about 6 mag. for my 8" Newtonian) to allow comfortable guiding. With wide field cameras this is usually not too serious a problem because one can always guide on a nearby bright star and offset the camera a little if necessary. All pictures presented here were made with the guide eyepiece described. The reader can judge for himself.

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АКАДЕМИЯ НАУК СССР

ИНСТИТУТ НАУЧНОЙ ИНФОРМАЦИИ

12.51.43. «Конструирование телескопов», 1980, № 7. «Telescope Making», 1980, № 7 (англ.)

Содержатся статьи: Berry R. «20″ Ньютоновский телескоп на альт-азимутальной установке»; Hamler W. E. «Оборудование для фотографирования объектов небесных глубин»; Waineo T. «Портативная полировочная машина»; Cox R. E. «Улучшение телескопа. Ч. 2. Вторичные зеркала и их растяжки»; Genet R. et al. «Группа фотоэлектрической фотометрии» (рассказывается о любителях, проводящих фотоэлектрическую фотометрию небесных объектов); Woods A. L. «Полировка зеркала с большим радиусом кривизны».

◄3

Thank you for the kind words on TM, we certainly enjoy presenting the various articles for the TM readership. If I can be of further assistance do not hesitate to write.

Robert E. Cox
205 E. Elm Street
O'Fallon, Missouri 63366

Minimum Orders

Sirs / One problem for the TM is the growing tendency of non-retail distributors to set a minimum charge. For example: the Crayford focuser on my telescope "Peepsight" requires each eyepiece to be mounted in its own carrier tube. This means, for an ordinary battery of oculars, about a foot of brass or aluminum tubing in the 1.25″ ID size. I couldn't find any locally, so I asked my brother, who lives in Los Angeles, to see if he could find some. Sure he could — but the minimum order was $25- for which I could have ten feet of tubing. Big help!

Another problem: zinc plated hardware store stove bolts and machine screws, even if they are rustproof, may be all right for first telescopes, but when you get around to making a really sophisticated rig, you need, among other things, brass machine screws in several sizes and styles if the finished job is to look professional. Do you know where you can buy brass, filister head machine screws, in the #2-56 size, 1/4″ long? The only supplier I knew of stopped making brass machine screws three years ago, and I'm hoarding my pitifully small stock of brass screws and bolts as though they were made of gold.

Earle Dodds
703 Courtland Avenue
Muscle Shoals, AL 35660

— Can anyone help? I think a lot of people would like to know where to find those hard-to-get parts.

Another Source of Teflon

Sir / Another source for teflon in small quantities is:

Frank Wirt Electronics
Alpha, IL 61413

An SASE will bring his price list. Typical prices are $3.00 for a 4″ x 4″ piece of 1/8″ material. He also has thin stock (.003 to .030) as well as rods and bars. He welcomes small orders.

Re suppliers: may I put in a good word for Telescopics — with whom I have dealt intermittently for some twenty five years — always to my satisfaction.

I am very happy to have found your magazine. It revived my dormant interest in telescope making — so I am busy on a 14″. TM's only fault is its publishing schedule; quarterly is not frequent enough. I look forward to your success in eventually making it a monthly.

M.L.A. Scott
Box 557
Grants Pass, OR 97526

Scrambled Photos

Sir / The picture on page 3 of TM #9 was taken by me and not by David A. Young. Like Mr. Young, I had mailed you a letter describing my 4.25″ f/4 Mini-dobs which is based on a Coulter Kit ... obviously great minds think in similar circles!

An interesting variation on the Dobsonian concept is a Cassegrain with a Nasmyth focus. The focus could be on top of the tube box or in the center of the side bearing. A Dobsonian telescope with both a Newtonian and Nasmyth focus would be a very versatile instrument.

Bill Deane
312 Hermitage Road
Knoxville, TN 37920

—Sorry about mixing the picture credits. Most readers will have also noticed that the pictures in the TM#10 Astrofest article do not correspond to their captions, an aberration introduced by our printer.

Big Ideas

Sir / I am an amateur astronomer whose main interest is deep sky observing. I presently would like to move up in aperture from my present scope and I would like your help. I am looking for someone who makes thin porthole or plateglass astronomical mirrors, especially in the 20″ to 24″ range. Conventional Pyrex mirrors of that size are much too heavy and expensive for me. However, looking through advertisements in the astronomical publications, I couldn't find anyone who offered finished mirrors in that range (20″-24″). I would be very grateful if you could help me somehow in this regard, say, if you might know someone who makes and sells these thin mirrors.

Being editor of Telescope Making magazine, you certainly have more access to these matters than I have! Once again, If you can help me in any way it will be tremendously appreciated.

Jeffrey Pignatira
83 Homestead Drive
N. Tonawanda, NY 14120

— Right now, I know of no suppliers of 20″ to 24″ thin mirrors. For most opticians, the work to produce a large thin mirror equals or exceeds the work to make a full-thickness mirror, so there is only a small savings. They also fear that large thin mirrors will be inadequately mounted, perform badly, and therefore hurt their reputation.

Let us repeat, once again, that Pyrex sheet is preferable to plate glass sheet unless cost is a totally overriding factor, in which case you should grind and figure the optics yourself. If you intend to have the work done, most of the cost will be labor, and the savings of using plate glass will be lost.

A large telescope is a large project — whether it's a Dobsonian or not. I would like to remind potential builders to carefully consider all the costs and effort involved. Dream, but dream cautiously.

Cutting Circles

Sir / Your coverage of Dobsonian telescopes and their construction has been excellent. However, I can see one omission. As Bob Kestner pointed out in his article on Dobsonians, sheets of Pyrex are much cheaper than molded blanks. Yet how does the amateur cut discs of glass in the 12 to 20-inch range? Any ideas on this?

Rick Baier
Box 1595
East Canton, OH 44730

—Cutting circles out of heavy glass is described in How to Make a Telescope *by Jean Texereau. It would be best to purchase a circular blank from the glass supplier, however, who has the tools and experience. It's more expensive, but involves no risk of breaking the disk in cutting.*

Teflon* Legalities

Dear Mr. Berry/ It has recently come to our attention that Du Pont's well-known trademark Teflon* has been used

improperly as a generic throughout the excellent articles in "How to Build a Dobsonian Telescope", a reprint from Telescope Making magazine.

Teflon* is DuPont's registered trademark for its fluorocarbon resins and films. I am sure you can appreciate the fact that Du Pont has invested considerable effort and expense in promoting the trademark TEFLON*. We would be in danger of losing this important property right if we were to allow or condone the use of the mark as a generic.

A booklet setting out correct use of the trademark TEFLON* is enclosed. May we have your written assurance that TEFLON* will be recognized as a registered trademark in all future printings of "How to Build a Dobsonian Telescope"?

Very Truly Yours,
Charles C. Adams
Legal Department
E.I. DuPont de Nemours and Company
Wilmington, DE 19898

Dear Mr. Adams/ Thank you for informing us that Teflon is a trademark. As you are probably aware, the term "teflon" is already in wide use as a generic, as kleenex and scotch tape are, by the technical community. We do not think it would be feasible for us to change all type in our booklet to conform to the useages shown in your booklet. However, we could easily add a notice at the front of the booklet stating that "teflon" refers to TEFLON®. Furthermore, I notify TM's readers that it's TEFLON® not teflon. —RLB

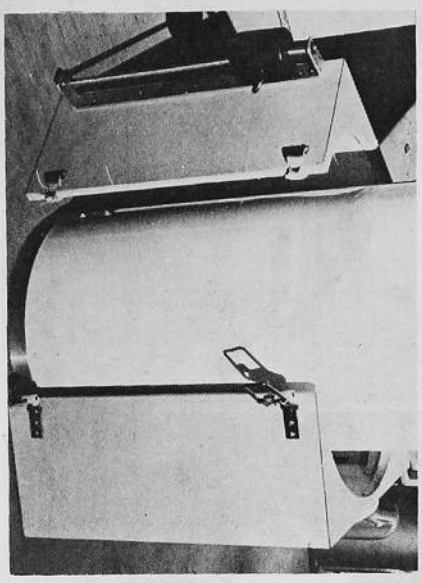
—Okay guys, the jig's up. They got us. From now on, read "Teflon", TEFLON, Teflon®, or Teflon for teflon in TM.*
**Du Pont's registered trademark for its fluorocarbon resins and films.*

Clamp-on Tube Box

Sir / I am enclosing a picture that may be helpful to those who want to transfer their telescope tube to a Dobsonian mount. After making my tube box, I cut it in two, hinging one side with piano hinge and using two heavy duty suitcase catches on the front side. In making the saw cut, I removed enough material to give me a ¼" gap.

Notice the soft rubber bumpers under the catches — this enables me to open the catches, rotate the tube when needed, and by spreading the halves of the box, remove the tube easily. Not shown is a ring fastened to the tube that acts as a bearing on the top of the box, and also does the same thing on the equatorial. Being able to remove the tube box also makes the scope easier to load in a wagon.

My whole Dobsonian unit is covered with formica; I had scraps on hand in four



patterns, and used mahogany molding for all the edges. It makes a very attractive and easily cleaned unit. The telescope itself is a 10" Meade f/6.

I have made Dobsonians in these sizes: 12.5", 6" f/4 tabletop telescope, and 4.25" f/11. All I do is lay out a pattern to check clearances and get a balance point. PVC pipe is excellent for bearings — and of course teflon is a must for the pivots. I have also made a Poncet for the 6" f/4, but have not used it for photography — but as you say this is coming!

I enjoy your magazine. For the experimenter there is a load of good ideas and suggestions in every issue, and a world of information for the advanced telescope maker or observer. My next project will be some type of 'house' for the equatorial that I have 'planted' in the backyard.

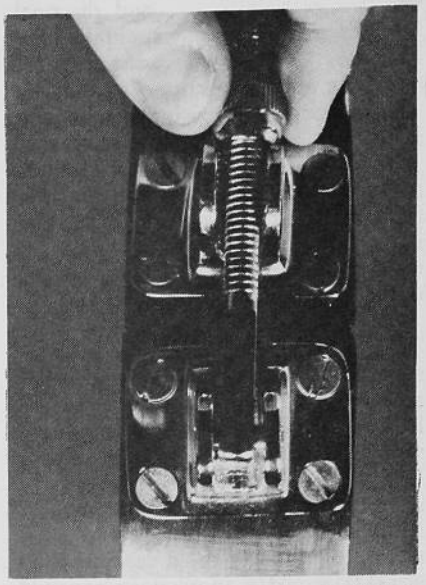
R.V. Whitney
408 S. Avon
Gastonia, NC 28052

Boatyard Cradle Clamps

Sir/ In constructing a cradle for a heavy brass five-inch refractor, I was presented with the problem of finding latches for the rings which would have adjustable tension, yet be extra strong. Such latches can be obtained at a boating supply store. They are chrome-plated steel, consisting of a threaded toggle, bearing a nut which fits into a socket in the opposing half of the latch. Tension can be adjusted, or the latch released, by screwing or unscrewing the nut. When the latch is closed, and the nut advanced snugly up into the socket, the toggle cannot pop out.

Total cost of two latches and two hinges is about $35.

The rest of the cradle is cut from rock maple, reinforced with hardwood dowels through the upper halves of the rings,



and four-inch lag screws on each side of the lower halves.

Eric Rachut
3296 Pennington
Afton, MN 55001

Rekindled Interest

Dear Mr. Berry / Here is my subscription renewal for TM; keep up the good work. I'd like to tell you what I like about TM and what I'd like to see in the future. But first, a little background.

After 15 years away from astronomy and telescope making, I found a copy of ASTRONOMY magazine in the company library one day last year. The articles and pictures rekindled my interest in the heavens. Recently I resumed work on an 8" f/7.5 mirror that I started at the Brashear institute in Pittsburgh under the direction of Glen Winterhalter. When the outside ¼" refused to polish out, I consulted Myron Emmerson, the author of a fine little book called *Amateur Telescope Mirror Making*. He helped me to figure out that the problem was caused by a slightly oversized ceramic tool which flattened the edge of my mirror. I've now returned to fine grinding, after reducing the tool diameter with the help of an electric grinder.

I enjoy virtually all of the articles that have appeared in TM, but I find three types particularly interesting: those that I call Personal Experience, Standard Design, and Theory/Technique articles.

Personal Experience articles describe specific problems and how they were overcome. I may never have a pre-war Chevy and an antique bathtub from which to make a telescope mount, but the ingenuity of others is an inspiration.

Standard Design articles, like the Dobsonian series or Robert Cox's articles on mirror cells ➤

and diagonal holders are great, especially for beginners like me who want a "safe" design for a first telescope. They help us avoid errors made by others over the years.

Theory/Technique articles include those on Dobsonian Friction and the Poncet Mount articles of TM #8, and numerous articles on mirror testing, lap making, etc. which, I'm sure, will be useful to me as my effort continues.

In the future, I'd like to see more Theory/Techniques articles on subjects such as the use of epoxy and other adhesives. I'd like to see a Standard Design article on spiders, with more nitty-gritty detail than that in the recent Cox article. More projects discussing observing aids would be useful, too.

If TMs with woodworking but limited metalworking tools could describe their projects, they'd be appreciated, as would information on locating and dealing with machine shops, and on learning metalworking skills. Generally, if there's anything I'd like, it's more information on how things were made.

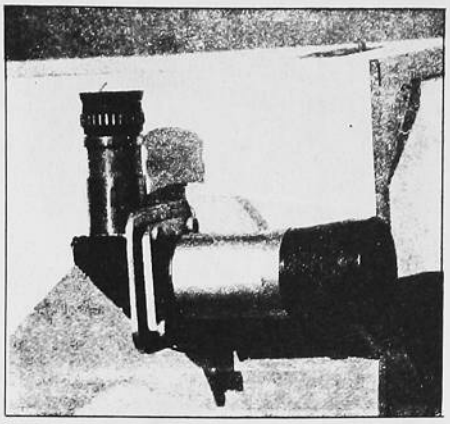
Thanks for doing a great job on TM so far, and good luck in the future.

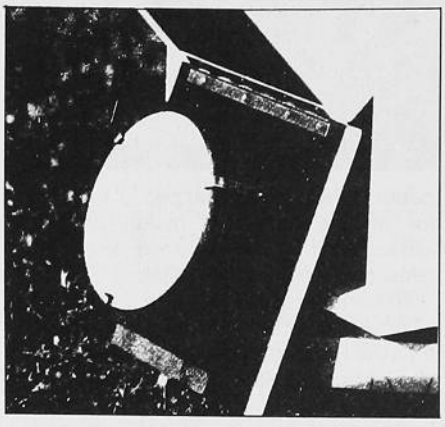
Fred Brosi
11024 Wood Elves Way
Columbia, MD 21044

—I hope that readers qualified to write the types of articles you're looking for will take note of your comments and submit articles to TM. I would like to see more detailed discussion of how things are put together, including, if possible, sharp b&w photographs and dimensioned plans. —RLB

FAS Dobsonian

Sir / Enclosed are two articles on the "Dobsonian" which you may find of interest. The shorter article will appear in the January 1981 issue of the Federation





Journal *and the longer one will be published in the 1981 edition of the* Federation Handbook *due out in March.*

We trust you will receive some subscriptions as a result of these literary efforts.

Peter O. Montgomery
President
Federation of Astronomical Societies
28, Shirley Drive
Worthing, Sussex BN14 9AY
ENGLAND

—Good news travels quickly. We are pleased that the Dobsonian has now crossed the Atlantic.

Aloha Skies

Dear Mr. Berry/ After seeing you at the Riverside Telescope Conference at Big Bear, some very exciting events came my way in regard to advancing the cause of amatuer astronomy that you may find of interest. Hence this letter.

At the conference I met and subsequently became a friend of the founder and president of "Telescope World", Mr. Gian (John) Sclippa. In the following months, I placed an order for their 16″ f/5 Newtonian scope with a 6″ f/5 richest field telescope attached. John and Jeff arrived, with the scopes, on the Big Island — Hawaii — last Thanksgiving, where I had been living since August of 1980. It was a great surprise to me and disappointment to discover there was no group of amateur astronomers on the whole island.

Soon I made the acquaintance of Dr. Rene Racine, the new director of the Canada-France-Hawaii Telescope facility atop Mauna Kea. It was a delight to learn that he is an avid and actively interested amateur astronomer in Montreal. We both expressed our concern that on the Island with the best observing site in the world, as well as some of the biggest telescopes, that there was no amateur group. Also, unfortunately, some small-minded local politicians had been, and still are, opposing any and all new telescopes on the mountain — especially the newly proposed 10-meter CalTech telescope. Dr. Racine assured me that I would have his help and the assistance of his staff if I could get a group started.

Thus, I found myself in a position I never imagined or desired to come my way, namely, trying to found a new astronomical society where none had previously existed. The few times the CFH people had tried to hold lectures for the public in the local library had met

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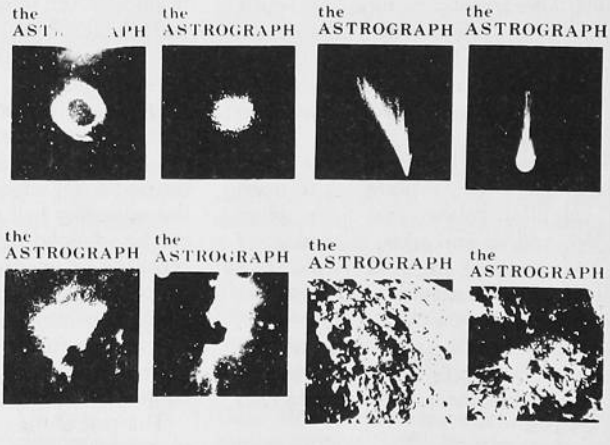

with little success, so this was not encouraging.

Then a very interesting event occurred. One weekend later, I took my wife to the Mauna Kea Beach Hotel at Kawahii about ten miles from our place on the dry side of the island for her birthday — and we ended up staying overnight. Because the sky was so dark and clear and warm, I decided to go home and get my AstroScan and C8 to bring down to the hotel and observe in their north garden. On the way into the hotel with my equipment, the night manager, a Britisher by the name of Wilcox, stopped me and asked if I would like to share my scopes with other guests. So, he made an announcement and 30 minutes later there were over 50 guests looking through the telescopes in the north garden. This went over so well that the next day all three managers of the hotel asked if I would be willing to give monthly astronomy shows at the hotel. They made the auditorium available to me and any guest speakers I cared to invite.

Our first astronomy presentations were held using my slides of deep space objects and the 1979 Solar Eclipse from Helena, Montana. Dr. Racine talked about the relationship between professional and amateur astronomy and showed slides of the CFH telescope at our first meeting. It drew a standing-room-only crowd in the auditorium — and several hundred people to the telescopes at the north garden of the hotel. Some of the guests even set their alarm clocks for 4 a.m. to get up and see the Moon and the planets.

The second meeting at the hotel coincided with the Voyager 1 flyby of Saturn and the arrival of my Newtonian 16″ f/5 from California. (John Sclippa and Jeff Carmac decided to take their vacation in Hawaii and bring the scope with them.) This time the show was bigger than the first and we ended up staying the whole weekend at the hotel. We showed JPL and news video tapes of the Saturn flyby. The four telescopes set up — the 16″, the C8, C90, and the AstroScan were mobbed. The crowds didn't thin out until after midnight, with many people again setting their alarms to arise early to observe the 3rd quarter Moon, Jupiter, Saturn and Venus in the predawn sky. At this show we met many celebrities such as Donald Sutherland, the actor who happens to have a C8 and others. People were wanting to know how to get in astro clubs in their areas, buy telescopes, etc.

After the second astronomy show at the Mauna Kea Beach Hotel I met the physics director of the Hawaiian Preparatory Academy, a prestigious private high school on the Big Island, who has a minor in astronomy and

teaches astronomy at the University of Hawaii, Hilo branch. At the same time that I met the physics director, I met the editor of the local paper and became involved in the Santa's Observatory parade in Kamuela, the special Christmas event to honor the CFH telescope people in that town.

Then in rapid succession followed a tour of the CFH telescope on Mauna Kea with John Sclippa and other friends, and the founding of the Mauna Kea Observers, the new astronomy club on the Island. I am the founder and president of the club, and Rod Kehl, the physics director at HDA is the acting president in my absence (I periodically sail as a radio officer on merchant ships), and Brian Wyatt and his son are vice president and secretary. Brian is the purchasing agent for the Mauna Kea Beach Hotel.

Dr. Racine and Dr. Bruce Cambell have joined the club as lecturers and consultants. Rene is the director of CHF telescope and Bruce is the resident astronomer at CFH.

We had our first Mauna Kea Observers star party at Hapuna Beach State Park located a mile from the Mauna Kea Beach Hotel on Saturday, December 27th. In spite of an hour of rain from 10 to 11 o'clock, we managed to have several hundred people throughout the night. (Other than the hour of rain, the rest of the night was clear.) As before, people who had viewed early in the evening returned early in the morning to view the Moon and the planets.

Since these events, I have returned to California to take a ship out of San Francisco. My wife and kids will remain at my home in Kamuela. I've loaned my 16″ f/8 and C8 to the upper campus of HPA in my absence, and my wife informs me that the school has kept the club going — they had two star parties already this month with Rene Racine giving astronomy talks at the meetings. Also, HPA, in cooperation with the University of Hawaii, is trying to erect an observatory down at the Parker Ranch Beach or on the top of Mauna Kea to house my telescope. The CFH and U of H people are making one of the 24″ telescopes on Mauna Kea available for amateur use, and the CHF people are talking about possibly purchasing one of Telescope World's 16″ Newtonians for a public Observatory in Kamuela. The local paper has been running articles on me and the new astronomy club. Quite understandably, I am shell-shocked from all this and wonder if I'm not in a dream — but it's all true!

I have had a chance to thoroughly check out and star test the Telescope World 16″ f/5 on Mauna Kea and in my backyard in Kamuela. It's tracking and optics are a dream compared to my C8. As I make duplicate and enlarged slides of my originals, I'll send them to you. Enclosed with this letter, you will find some preliminary results. These prints are nothing compared to the slides. I have succeeded with the use of the 16″ and the Lumicom Hypering proccesses in getting some good results with E-400 in ten to fifteen minute exposures. Some examples, the Owl Neb in color with eyes 10′, M-101 with meteor track 15′, NGC 5128 in 15′, and so on. With the hypersensitized film I find sky fogging on Mauna Kea in 20 minutes. The nights I was on the mountain, the telescope people told me they recorded 1/3 sec arc seeing.

Berry, you would have to see the sky on Mauna Kea to believe it! Stars resolve as perfect non-fuzzy or flaring points in the 16″ at high power. No star twinkling even at the horizon. Sirius high in the sky with Canopus below. Later in the night, the Southern Cross on the Horizon with Alpha and Beta Centauri, and the Eta Carina Neb, and Omega Centauri plainly visible to the unaided eye — and incredible through the telescopes. The views in Hawaii are so good that I am glad I left my telescopes (with the exception of my 11 x 80 binocs, which I take aboard ship), lest I suffer severe disappointment in California. The planetary observing on the mountain was no less exciting. Jupiter and Saturn look like Voyager shots through the 16″ at 600x.

Well, this has turned out more lengthy than I expected, but I guess my enthusiasm about these recent experiences caught up with me in the retelling of this story.

Clifford Livermore
General Delivery
Kamuela, HI 96743

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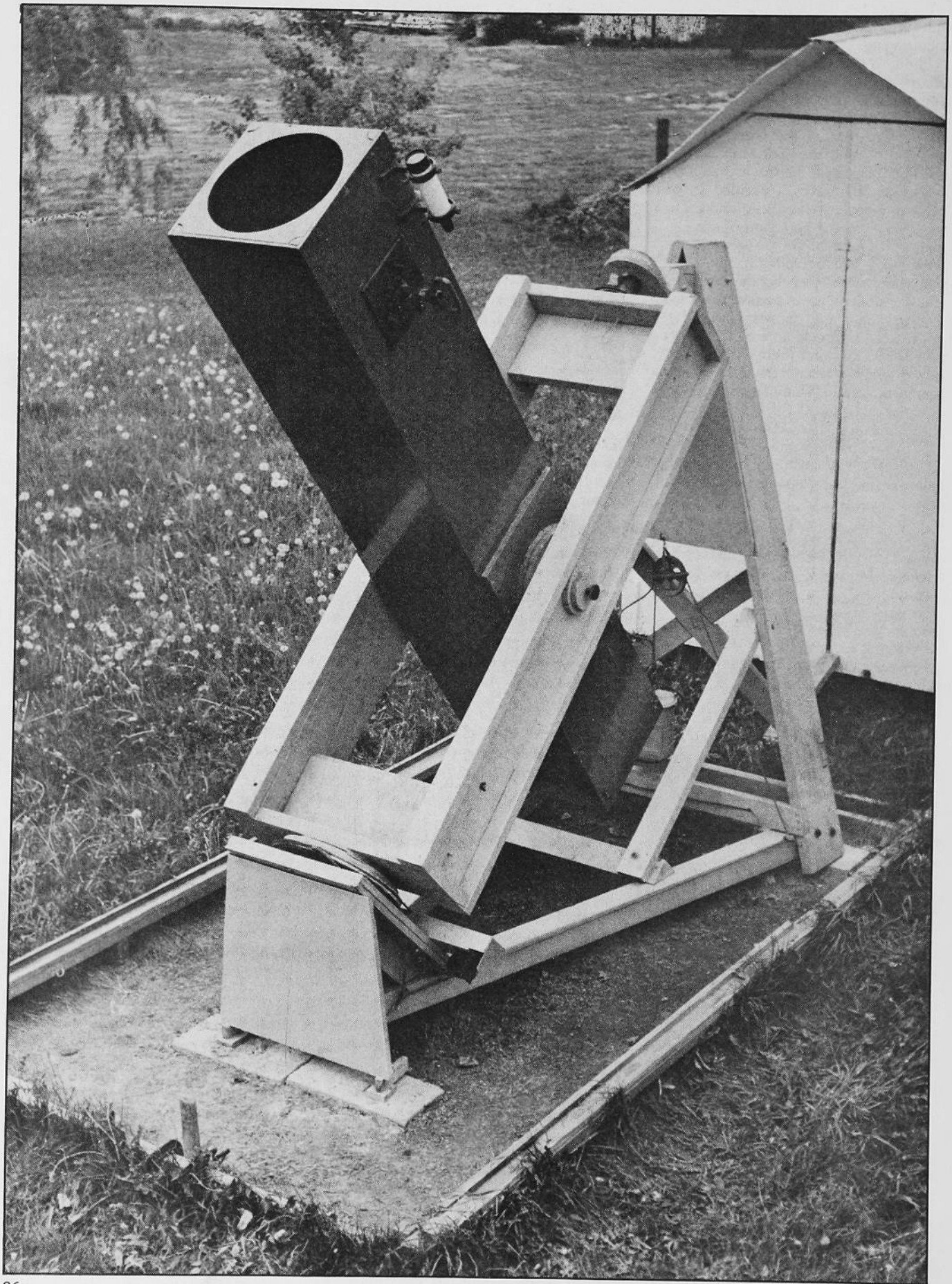


Yoke and Cross-Axis: Mountings Made Easy

Shaky telescopes bother me. I've always tried, though I haven't always succeeded, to place each of my telescopes on the steadiest mount I could construct. Like many others, however, I've often been limited by costs, by my knowledge, and by my skills. Nevertheless, I've constructed several very satisfactory mountings for medium to largish homemade telescopes — mountings that are not only quite steady by amateur standards, but can be constructed with relatively simple tools and limited experience.

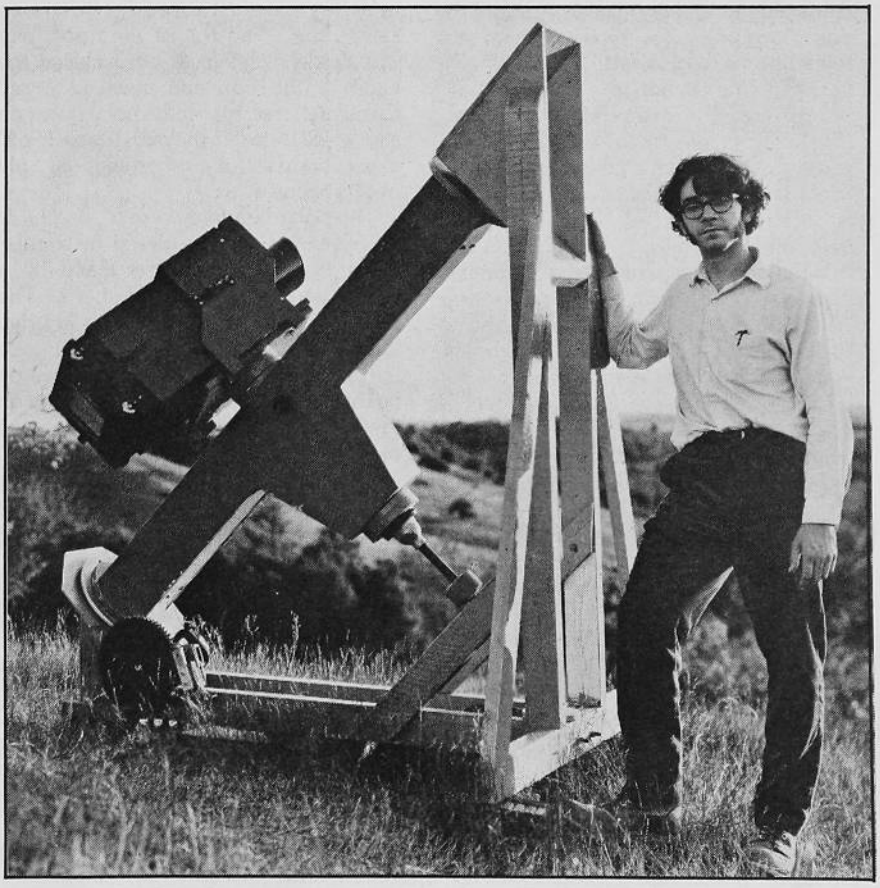
These mountings achieve stability partly through design, and partly simply by placing modest demands on their materials. The designs are the yoke type mount, familiar because of the 100″ Hooker telescope on Mount Wilson; and the cross-axis, or English design, seen on the 36″ Crossley reflector at Lick and the 72″ and 74″ telescopes at Dominion and David Dunlap Observatories in Canada. In both types of mountings, the telescope is supported *between* the polar axis bearings. Also, the distance between the bearings is many times greater than the diameter of the primary mirror.

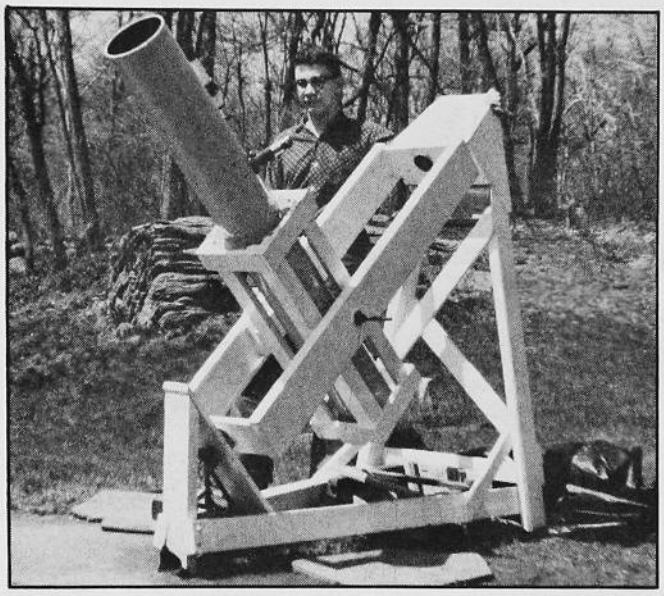
Let's consider some of the functions and requirements of a telescope mounting. A telescope mounting supports the telescope, and ideally, it should support the telescope as solidly as if the telescope were resting directly on solid bedrock. However, since we wish to point the telescope in different directions at the sky, and we wish as much freedom in doing so as possible, the telescope must be able to move about two mutually perpendicular axes. Many times, we want the telescope to remain accurately pointed at an object for some time, and to meet this requirement in the simplest way, we can set one axis parallel to Earth's rotation and drive it at the same rate as the Earth turns. The mounting itself need *not* be strong, provided it can support the weight of the telescope, but it must be rigid and must dissipate the vibrational energy inevitably introduced by wind-loading (and the observer's clumsy fumblings) rapidly.

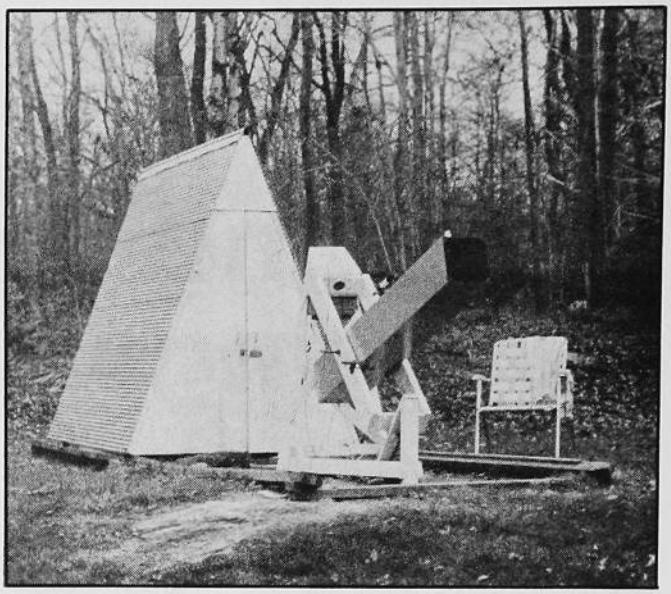
How can we best satisfy these requirements?

In materials choice, there are several traditional and successful approaches to building a steady mounting. One consists of massive hardened metal components machined to close tolerances turning on precision bearings, with high-stiffness members supporting the whole thing. This approach, which I would love to take if I could, is difficult and relatively expensive. Another approach, the Porter's Folly method, advocates massiveness, or an inertial approach to suppressing vibration by simply making it difficult to start.

I've tried the third approach: rigid cross-sections of non-metallic materials with broad energy-dissipating contact surfaces. In practical terms, this translates as squatty looking wood and pipe mounts.







How can you build these? Think of your materials as weak. Don't load them heavily. Plan to soak up vibration when it does occur. Assume your materials will flex. Don't concentrate stresses. Build big stationary and moving contacts to convey vibration to sinks. And introduce lots of energy-dissipating friction where moving parts meet.

Besides the materials, rigid design techniques, and vibration damping, the geometry of the mount is important in attaining stability. I chose the yoke and cross-axis mountings because they are both "long polar axis" types in which the telescope is supported "inboard," or between the bearings. This reduces flexure greatly. Furthermore, since the frequency of oscillation is higher, it is easier to damp out. Yoke mounts are "doubly inboard" because the telescope is also supported between the declination bearings.

What good is separating the bearings? The axes of "outboard" mounts — the "singly outboard" such as the fork, or the "doubly outboard", such as the German equatorial — are cantilevered. The unsupported end can vibrate freely. There are regions of high stress at the bearing, and the weight of the telescope may be tripled or quadrupled by the lever arm of the fork. Finally, a small amount of movement or flexure in close bearings moves the axis through a large angle.

Now let's get down to the specifics of four mountings of this type. The first was a lightweight yoke modeled on photographs in *ATM-1*. My father and I built it when I was 13. It carried my 6″ f/7 for a few years and later an 8″ f/10. Next is a heavy-duty yoke built of 3″ x 9″ oak timbers from a house-wrecking place, with a concrete block pier. It carried my 12″ f/7 for about 6 years. The third is a weatherproof cross-axis mount I used mostly for photography with a 24″ Aero-Tessar lens. And fourth is the yoke mount that carried my 12″ from 1973 to 1976 — the mount that's come closest of any of mine to having a really good clock drive.

The first mounting could be built in a few days by virtually anyone with a Skil-saw, drill, and screwdriver. The north and south piers were constructed as a single structure made of 1 x 4s and 2 x 4s, bolted and screwed together. The angled plate on the south pier, made of ½″ plywood, should have been slightly heavier or reinforced, but was satisfactory. The top of the north pier was made of ½″ plywood. I closed the back of the box and installed a red Christmas tree light that shone down on an eye-level shelf in the pier. I used 3″ x 5″ index cards for recording all my observations.

The polar bearings were 6″ lengths of ½″ brass rod silver-soldered to circular brass plates. They were made by a machinist friend of my father's. The south one was threaded so a knurled knob could act as a clutch to adjust the tension on the bearing. The declination bearings were ½″ brass rods threaded on the inside ends. They passed through a brass bushing attached to the sides of the yoke and entered plates attached to the telescope tube box. By unscrewing the declination studs, the tube box could be carried inside. ¾″ pipe would have worked just as well as these machined brass parts. The mounting was left outside covered by a large plastic tarp.

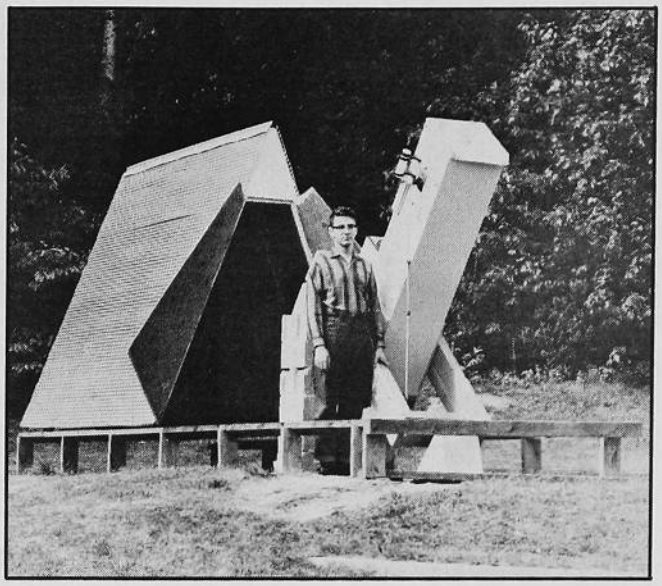
The yoke was made of ½″ plywood sides 6″ deep. The east-west sides were flanged with 1¼″ wide pieces of ½″ plywood. The north and south ends were also ½″ plywood. It amazes me now that ½″ plywood worked so well: if I were to build it again today I would use at least ¾″ plywood. Although the yoke was fairly limber, the vibration was from side-to-side, so the image in the telescope did not shake.

The tube box was made of hardwood boards. For clamping and fine control in declination, I set a carpenter's clamp on the yoke against the tube box. By loosening the clamp slightly and squeezing it against the tube box, I had a delicate method for moving the telescope a small amount in declination.

The telescope tube rotated inside the box on a plywood and aluminum ring attached to the tube. At the bottom end, the tube and box turned on a short axle of ½″ brass rod. The telescope was a 6″ f/7 reflector, which I still use today. The tube was unusually long for shielding from light.

After several years with the 6″, I built an 8″ f/10 reflector with a square wooden tube and used it in the same mount. The mounting continued to perform well, even at very high magnification (I frequently used 480x for observing Mars), despite the greater length and bulk of the long-focus telescope. I also built a light A-frame roll-off observatory sheathed in corrugated aluminum (dubbed "the chicken coop" by my family), that ran on rough-sawn 2 x 6 tracks on the ground.

Because the yoke mounting had been successful with the 6″ and 8″, I decided to use the same type of mounting for a 12″ telescope. In late fall 1963, I dug holes down to bedrock for the piers of the new mount and filled them to ground level with concrete. We ran an underground power cable from the house and brought it up through the concrete of the north pier. Three blocks high on the north pier, I brought out a box for electricity, then finished the pier up to six blocks high. We filled the hollows in the blocks with rubble, rock, and concrete. After it set, I built plywood forms for the stubby south pier and the upper section of the north



pier. The bolts for the polar bearings were placed in the forms and cast into the concrete. Since it was late fall, the leaves were off the trees, so it was possible to check the location of the north polar bearing against Polaris before pouring the concrete. We kept the observatory building in place and heated the curing concrete with light bulbs through a cold spell after the concrete was poured.

The yoke was made from a 3" x 9" oak timber obtained from a house wrecking firm, and was roughly 20" wide inside and 65" long. The corners were mortised, nailed with 6" spikes, then filled with liquid epoxy resin. I bored two holes to fit 1½" pipe declination axis stubs tightly, and attached a length of 2" pipe to the north end of the yoke with a floor flange. For the south bearing, my father found a 1" stainless steel shaft in a self-aligning pillow block on a scrap heap, and we bolted it to the south pier.

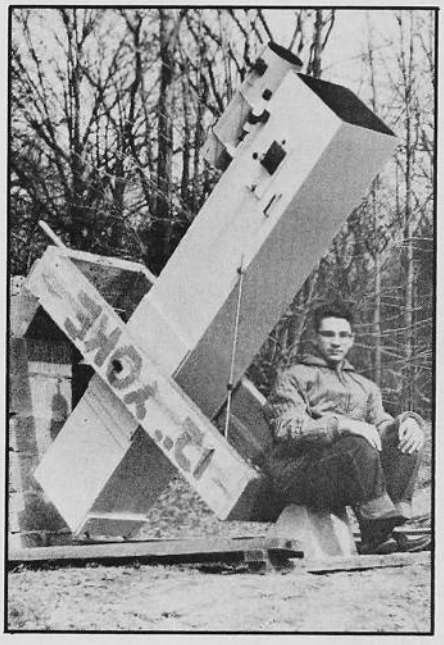
The declination axis pipes were run into floor flanges, and these were attached to the sides of the tube with wood screws. To clamp the telescope in declination, I attached a ½" aluminum rod to the yoke and to the side of the tube with chemical rod system clamps. In right ascension, the telescope turned freely without any clamps. Since it stayed put where it was left, none were necessary. The northern bearing was a softwood vee-block bolted to the concrete, which I shimmed for altitude and pushed back and forth for precise polar alignment.

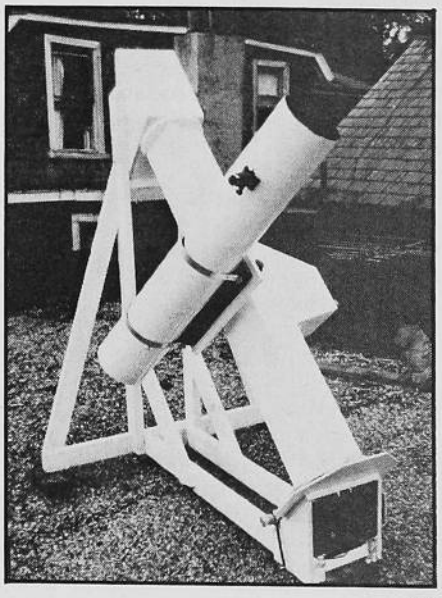
Since I used the telescope primarily for visual observing and short exposure (1/5th second and less) photographs of the Moon and planets, I did not initially try to build a drive. When I wanted to try longer exposures, I built a number of rather poor tangent arm drives. Using the 12" to guide a piggybacked 6" f/4 RFT, I obtained 20 minute exposures, but the tracking errors were large because they were "observer-driven" rather than motor driven. (This is not a fruitful approach.) A year later, I tried another version of the same scheme, this time with a surplus 24" focus Aero-Tessar mounted on the back of the 12". Although the tracking errors were much smaller, they were not eliminated.

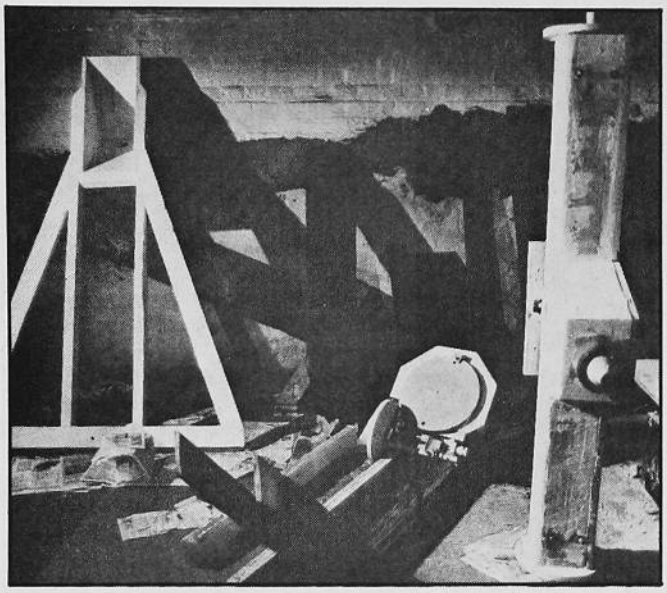
Because the observatory could not roll over the larger 12" mounting after the telescope was installed, the telescope spent its first winter under a tarp. In the spring, I raised the track 12" on rough-sawn 2 x 6s set in poured concrete footings. The ventilation provided by this space under the building seems to have been effective — the telescope was always cool and ready to use shortly after sunset, and the building stayed much drier inside than it had before. The raised track provided a scaffold for observing objects higher in the sky than I could reach standing on the ground.

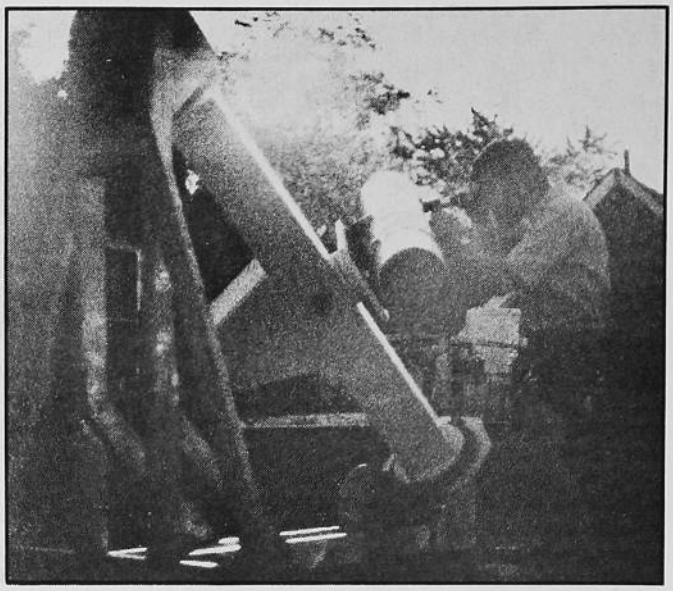
This mounting was exceptional in steadiness. I could focus without introducing vibration, and could even steady myself on the telescope when observing east of the meridian in somewhat teetery positions. The pier could be kicked, leaned against, and even climbed on without shaking the telescope. I recommend concrete piers as the ultimate in stability for anyone building a yoke-mounted telescope.

My telescope-building activities came to a halt for quite a few years while I attended college and graduate school. During the interval, my interest in deep-sky astrophotography grew. I started planning to get back into active amateur astronomy. I repaired and improved my 24" AeroTessar camera. I had constructed a number of telescopes over the years, and for greatest efficiency, I wanted to be able to use all of them as









well as the astrocamera on one mounting if possible. I started thinking about drives again, determined this time to solve the problem of building a good one without access to a machine shop. Then there were the logistics: since at this point I was living near downtown in a large city, I also needed to be able to operate the mounting at a remote site. I drew up the following list of "absolute" requirements for it:

Great stability
Great load capacity
Interchangeable telescopes
Drives on both axes
Transportability
Complete sky coverage
Tracking across the meridian.

The need to track across the meridian ruled out the German mount, and the need for interchangeability and complete sky coverage pretty much ruled out yokes. Forks seemed good, but promised to be difficult to build rigid — especially to support a 60-pound astrocamera. The need for different spacings between the arms also presented problems for a fork. It appeared to me that the declination axis, at least, had to be an "outboard" type, but for stability, the polar axis should remain "inboard." This pointed to the cross-axis as offering the "best fit" to my requirements.

For the drive, I ruled out all tangent arm arrangements and all gear arrangements which called for more machining than I could muster. Gear arrangements call for precise spacing and alignment between the polar axis and a base of some kind. I decided to give the drive disk, or some variant of it, a try. With a drive disk, little changes in the position, concentricity, or angle of the polar axis do not matter.

To make the polar axis very rigid, I adopted a box girder construction for it — a hollow box made of wood. From textbooks on the strengths of materials, I calculated the rigidity of various wooden boxes, settling on a box 8″ x 8″ made of two 2 x 8 pine boards and ¾″ plywood sheathing as reasonably light but as rigid as a 3 x 5-WF steel I-beam. I determined the length of the polar box by the length of the largest telescopes that would be mounted on it, then designed the piers to support it yet clear the telescopes and counterweights.

For several years, various friends and I had been building telescopes interchangeable between our pipe mountings. We had agreed on a standard base plate all our telescopes bolted down to. I designed the declination axis to carry this baseplate on 2½″ pipe, but rather than hang any weight on a length of unsupported pipe, I built a wide contact surface between the plate and the polar box. The pipe bearing points were placed as far apart as possible: 18″. The net result was a tight bearing that transmitted vibration from the telescope into the mounting over an 8″ diameter contact.

The polar box was assembled with threaded rods, large woodscrews, and lots of glue. The pipe stub at the upper end was epoxied into two heavy blocks of pine, and the bottom was drilled for ¾″ steel rod. To attach the box ends (which act as clutch plates) perpendicular to the axis of rotation of the box, I built a temporary lathe jig. The entire box was spun at 600 r.p.m. with a ¼-horsepower motor, and I turned both ends flat with a gouge. The disks at top and bottom were screwed on with the box on the turning jig to check for wobble adjusted until I could get a uniform pencil line all the way around the disk when the box was turning, then glued. The declination counterweight box and the side panels were added to the box last.

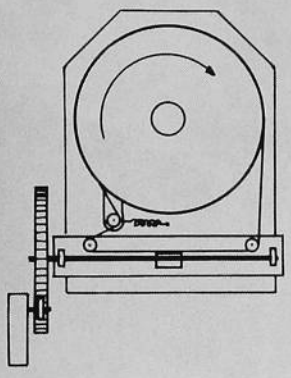
The pipe turns on plasticized wood. I drilled the openings for it slightly oversize, then painted them with coats of Panite plastic wood glue, then filed them until the pipe made a very tight fit.

The declination slow-motion tangent arm is located inside the polar box. A clamp made from threaded rod passes through the box, and enables the observer to clamp the 2 x 4 on the pipe tightly. The slow-motion is operated by turning a knob attached to threaded rod at the bottom end of the polar box.

The piers and base were made from lumber given me when our nextdoor neighbor tore down his rotting back porch. The wood was rough, splintery, and covered with ancient paint, but I was thankful for the well-seasoned 2 x 4s, and the price was right. After reworking them, I sealed all the joints with wood filler and painted the assembly to weatherproof it. For transporting, I would disassemble the mounting into its three large pieces, and strap it to the roof of my car.

For the first year, I tested the mount on the second floor roof of the house we lived in and got everything working well. During that year, I used it with the 6″ f/7, an 8″ f/16 D-K Cassegrain, and the astrocamera. In the spring of 1971, we took it out 30 miles into the country to a friend's farm. I kept the astrocamera and telescopes in the city, but two or three clear moonless times per month, would spend a whole night observing or photographing. During the next five years, the mount stayed in several locations in the country. It was unprotected, winter and summer, except for a piece of plastic over the drive. On one occasion, a cow pushed it over. I used it mostly for making 60 to 90 minute exposures with the surplus 24″ f/6 AeroTessar camera lens on 4″ x 5″ or 8″ x 10″ sheet film, guiding with a 2.4″

Cross-Axis Disk Drive



reflector with an illuminated crosshair eyepiece at 120x.

The drive system which did the tracking deserves mention — for it did the job well enough — but it was no gem. The system used a ½" aluminum disk 10" diameter (which I found scrapped) driven by braided copper grounding wire. The end plate of the polar box rested on a pin passing through the disk. A sheet of masonite served as clutch material between them. The braided wire was attached to an internally threaded aluminum block carried along by ⅜" threaded rod. The rod, in turn, was rotated by a 10" diameter plywood gear with 64 teeth driven by a 7-tooth plexiglas gear turned by a surplus 5 r.p.m. synchronous motor. The biggest problem with the drive was an intermittent wobbling of the block on the leadscrew — when the block wobbled, guiding required continuous attention; when it didn't, the drive could track very well.

A few incidentals: this mount had an electric power outlet on the polar box. This proved to be very handy. I used the power to light the crosshairs and heat the astrocamera lens. Because there was so much space on the polar box, various friends and I piggybacked lots of other cameras whenever I was guiding long exposures. On one night, we had nine cameras — 35mm and 2¼" square formats plus the AeroTessar — all going at the same time. Because the mount and drive were so simple, I was always able to make field repairs when something broke. I did find that it was preferable to arrive an hour or so before dark to carry out "preventive maintenance" before an all-night photo session.

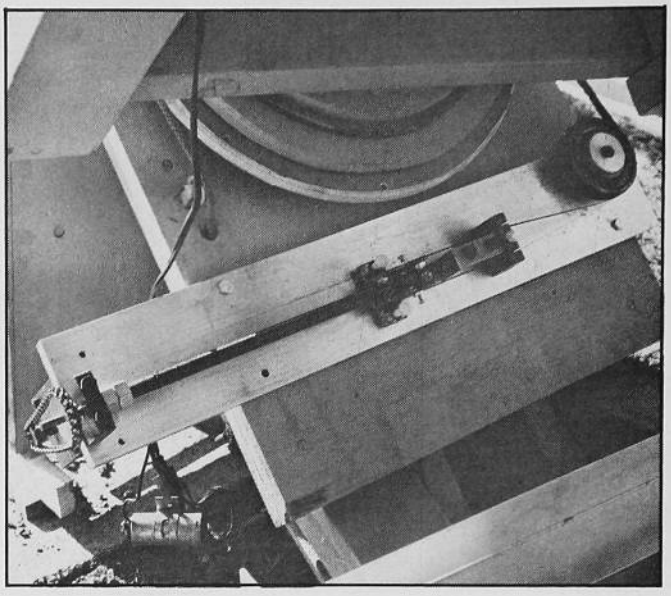
In performance, this mount was very steady except in two ways. Because right ascension motion was transmitted through a rather thin braided copper wire, initially it tended to oscillate slightly in R.A. on windy nights. In the second year of use, I installed felt pads under the drive disk to damp out this motion, but the extra drag was a strain on the braided copper wire, which would occasionally break.

Secondly, the north pier would twist if anyone leaned on it. (And with a big mounting like this, there's always

Astrophotos with Disk Drives

A 20-minute exposure with a 24" AeroTessar lens on the cross-axis mounting. 103a-F plate.

"When it was good, it was very good" — an unguided five-minute exposure of the Orion Nebula on Agfa 100 ASA film.



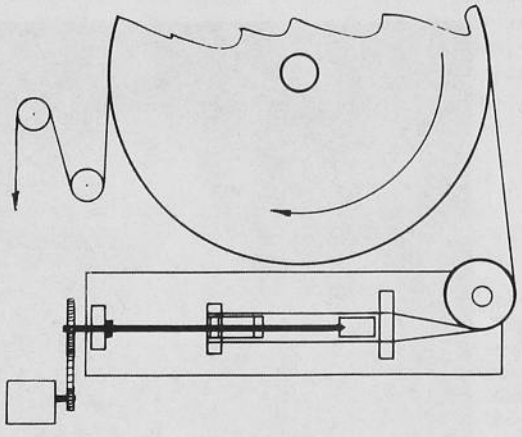
someone too tired to stand up himself.) I learned my lesson: the next time I built a north pier, I built it considerably heavier.

Shortly before I moved out of the city (to a rented house with a half-acre attached), I decided to get my old 12″ f/7 Newtonian mounted and operational again. After thinking over all the mountings I had seen and used, I opted once again for a yoke. I built it in the basement, then put it on the second floor roof in the city for testing. After moving, it became possible to place the telescope in an observatory building — once again a roll-off.

In building a new mount, I tried not to repeat any previous mistakes. For example, I reinforced the tube of the 12″ telescope with internal bulkheads. Although a square wooden box makes an excellent tube for a telescope, unless the corners are very strong, it may not stay square. Adding seven ¾″ plywood bulkheads cut to fit the inside of the tube made it far more rigid. I also mounted the eyepiece holder on an 8″ x 8″ platform attached to two bulkheads, rather than to the skin of the tube, for focal plane solidity. This platform made astrophotography with long projection setups possible, and was strong enough to support a 20-pound photometer head. The platform had a 4″ opening. Various eyepiece holders, cameras, and the mockup photometer (I moved again before completing the photometer) attached to a 6″ bolt circle.

I constructed the north pier from construction grade 2 x 10 spruce timbers, and much of the rest of the structure from 4 x 4s, using the structurally rigid triangular shape whenever possible. I used #16 x 4″ woodscrews and glue for the permanent joints, and ⅜″ bolts for all parts that disassemble.

12″ Yoke Disk Drive

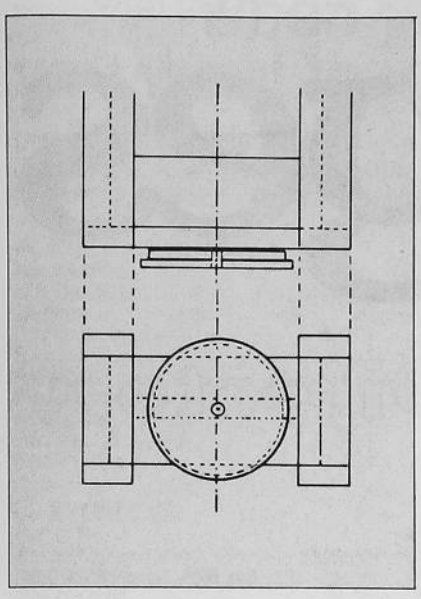


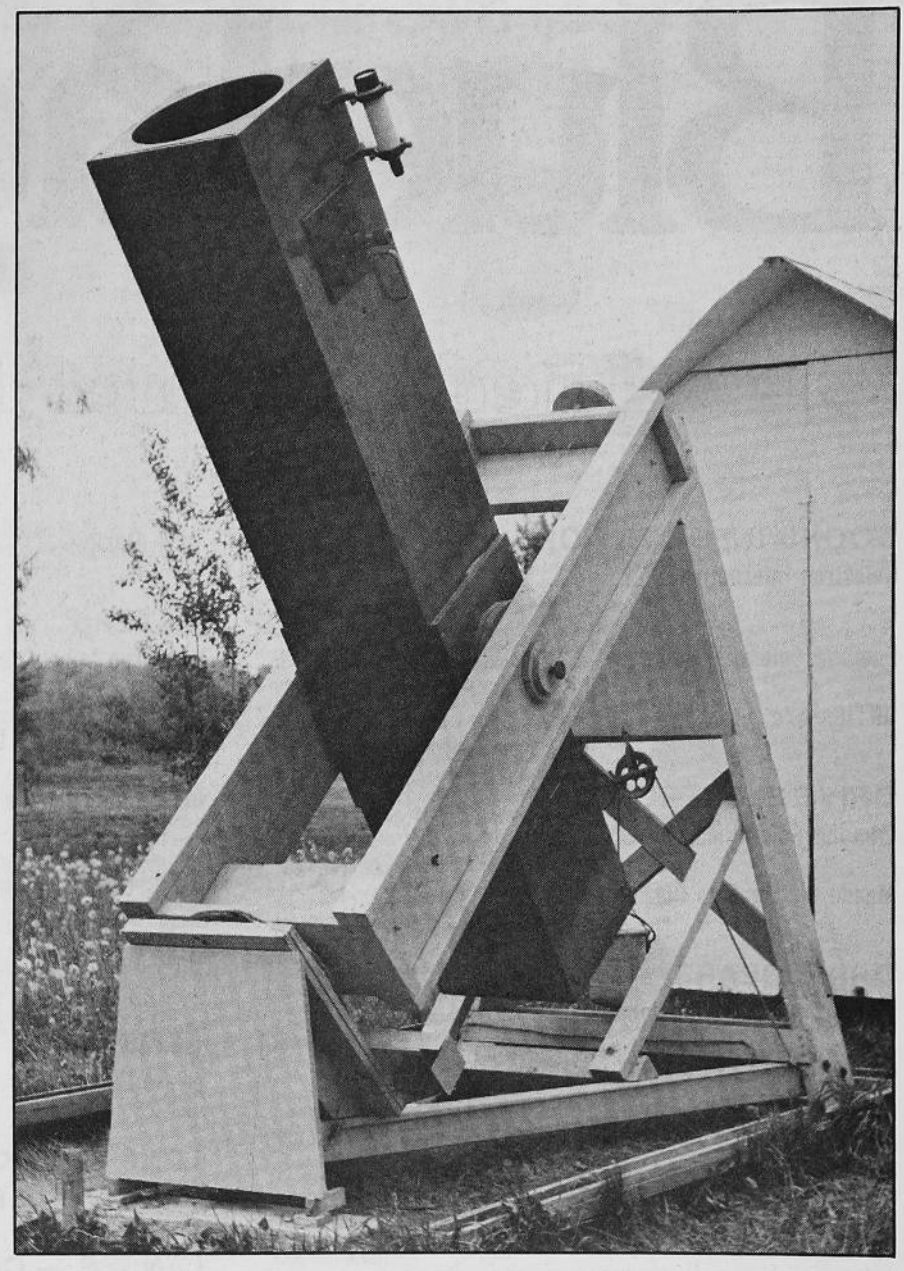
The yoke is made from construction grade 2 x 10s with 2 x 4 flanges glued and screwed on. At the north and south ends of the yoke, I placed a 2 x 10 web across the yoke. This added great stiffness because the sides of the yoke cannot oscillate without flexing the base of the yoke also. The stiffeners, even though they appear to shorten the yoke, do not limit the motion of the telescope, which can reach as far north as +73°.

Because of the weakness in the south pier on the cross-axis mount, I reinforced the south pier of the 12″ yoke heavily. It consists of two ¾″ thicknesses of plywood together and backed by 4 x 4s. The upright plywood sheet transfers torque from the polar axis into the ground. Thus, the mount rests on four points — two at the south pier and two at the base of the north pier — but because the base itself is not rigid, both ends twist slightly, and the structure behaves like a tripod at both ends, all four feet resting on the ground solidly.

The drive is a further development of the cross-axis drive. It is heavily constructed to pull against a heavy friction load added for damping with no strain. I eliminated the source of the wobbliness in the cross-axis mount's lead screw by loading the rider from both sides and by making the rider much longer.

The disk is another piece of aluminum shop scrap 16″ diameter and ½″ thick. To load the rider from both sides, the drive belt is split — two pieces of steel spring stock pass around a roller, split, and slide over bakelite guides to the rider. The rider assembly is made of two steel nuts and flat bar stock brazed together. A length of flat stock at right angles with two nylon screws that slide along the leadscrew base prevent the rider from rotating.





The leadscrew, 18" of ⅜" threaded rod, is turned to a 60° cone on its tip (the only lathe work in the whole project), riding in a 60° female cone made with a centering point in a brass block. A little hole drilled from the side permits lubrication. A 1-rpm synchronous motor (capable of delivering 120 in-oz of torque) drives the leadscrew through a pair of sprocket wheels and ladder chain. The ladder chain is a safety device: a link would open if the drive were to jam. The drive is good for over 6 hours of continuous driving before resetting.

Keeping a uniform preload on such a drive is critical, and the preload was the weak point in this system. I used a 40-pound weight pulling against the drive through a nylon rope. The rope passed over pulleys to the weight. The rope was elastic, and the pulleys didn't turn smoothly enough, so the preload varied, usually suddenly, stepping the telescope by 5 to 10 seconds of arc. After 3 or 4 minutes of tracking good enough for deep-sky astrophotography, I'd hear a little "tunk" as the rope sprung. I never got around to rebuilding this drive, which I am sure would have worked very well if the preload had been similar to the preload on the cross-axis mount drive.

The declination axis slow-motion employed a tangent arm 24" long on the east side of the yoke. Turning the clamp knob pulled a wood disk on the side of the telescope against the circular felt-covered upper end of the tangent arm. The declination bearings were two radial-thrust ballraces obtained from a surplus shop.

Besides being extremely steady, this mount offered a few pleasant amenities: a storage and work area in the north pier, space for large setting circles, as well as an intangible — it is simply fun to observe with a permanently mounted and massive telescope. The yoke design offers nearly all the advantages of fork mountings, but also provides stability not often seen in amateur-built forks. The small bearings required are inexpensive; polar alignment is simple; they can carry a tremendous amount of weight; there is space on them for an enormous drive — whether disk or worm gear; they track across the meridian; they're easy to build from simple materials. Since the telescope tube is supported from both sides, yoke mounts make the telescope tube easier to construct, and less prone to flexure.

On the other hand, reaching the pole is difficult, although not impossible (vide: the 200"), but making the horseshoe bearing does entail a lot of extra work. Cross-axis mounts reach the pole, and they have most of the properties of a yoke mount. Both yokes and cross-axis mounts are big and bulky — not at all suitable as portable mounts — but for an observatory telescope this doesn't matter much.

Yoke and cross-axis mounts have been "out of favor" for quite a while — perhaps mainly because so many recent medium-size professional telescopes have been fork-mounted. The next time you're thinking of building a mounting for a biggish telescope, forget fashion for a moment and ask yourself what you want in a telescope mounting. If it's stability in an equatorial mount — then consider the yoke or a cross-axis type.

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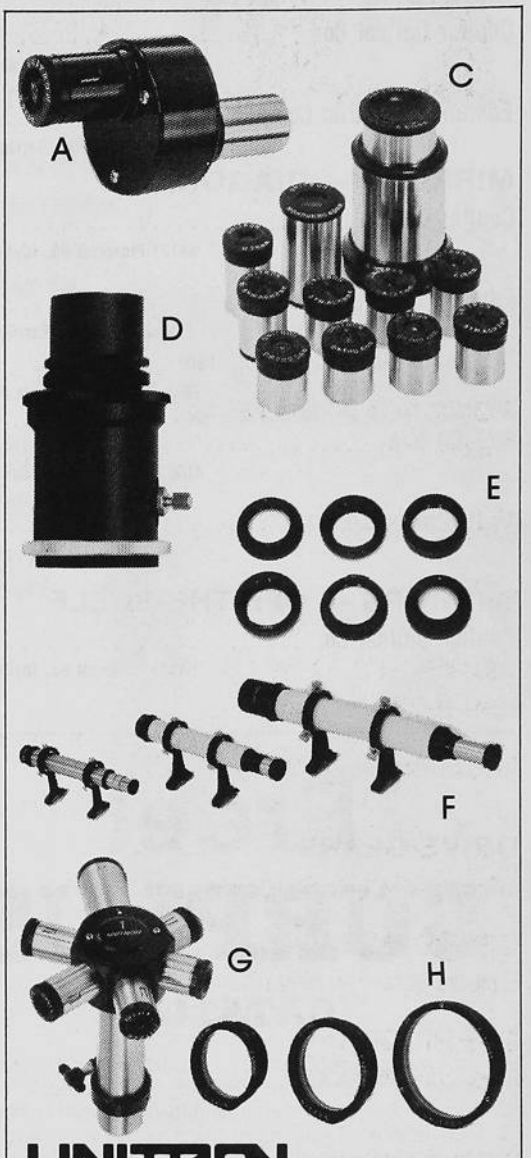

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